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Protecting People and Homes From Wildfire in the Interior West:

Proceedings of the Symposium and Workshop

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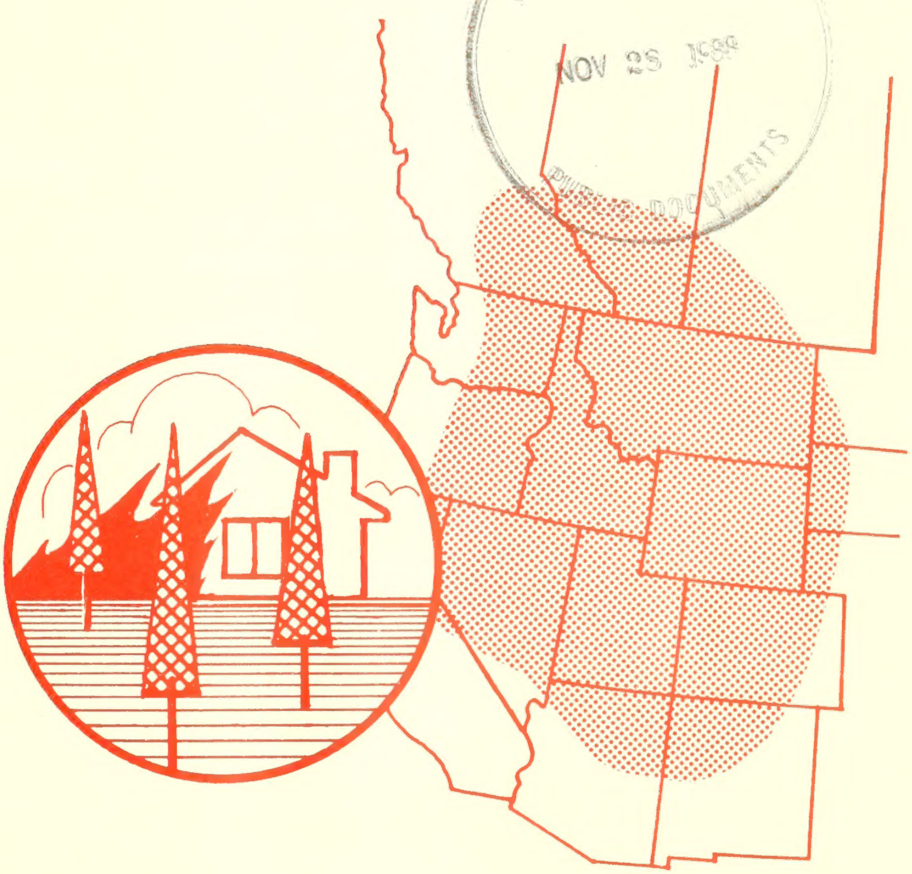

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

Protecting People and Homes From Wildfire in the Interior West:

Proceedings of the Symposium and Workshop

Compilers:

William C. Fischer, Research Forester
Stephen F. Arno, Research Forester

Intermountain Research Station, Forest Service
U.S. Department of Agriculture
Missoula, Montana

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U.S. Department of Agriculture, Forest Service, Intermountain Research Station

Montana Department of State Lands, Division of Forestry

Montana Cooperative Extension Service, Office of Extension Forestry

Society of American Foresters, Fire Working Group

University of Montana, Center for Continuing Education and the School of Forestry

National Fire Protection Association

PREFACE

Objectives of the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West were to:

1. Examine the problems of protecting wildland homes from fire
2. Reveal the threat of wildfire damage to life and property and the high cost to every taxpayer through increased taxes and insurance rates
3. Present state-of-the-art approaches to the home-wildfire problem
4. Develop recommendations for homeowners, government agencies, fire assistance personnel, and the business community to help solve the home-wildfire problems in the Interior West

During the 1970's, Federal land management agencies in the Interior West expanded their concept of wildfire control to encompass "fire management." Under this new policy they continued to suppress unwanted fires, but also adopted a more active role in preventing damaging wildfires through management of fuels, including the use of prescribed fires and other measures to reduce fuel buildup. "Fire management" resulted from the following realizations; (1) fire is a natural process, which for thousands of years has reduced fuels and regenerated forest, shrubland, and grassland vegetation; (2) human ability to suppress damaging fires remains quite limited; (3) human attempts to exclude fire often resulted in more damaging fires than would otherwise have occurred under a natural fire regime; and (4) on the other hand, people can manipulate the fuels (living and dead vegetation) so as to minimize damage from an unwanted fire.

At the same time that these concepts of fire management were becoming accepted in National Forests, National Parks, and some other public lands, on private lands the potential for economic losses and deaths was growing rapidly, corresponding with an increase in the number of homes being built in hazardous wildland fuels. In 1984, for example, four dozen homes were lost in a single fire in central Montana, and the potential for much greater losses throughout the Interior West continued to increase.

It was with these concerns that we met in 1985 with Steve Laursen, then State Extension Forester in Montana (currently Natural Resources Program Leader with the Minnesota Extension Service), to organize a symposium and workshop to address all aspects of the problem. Soon, this steering committee was expanded to include Gerry Baertsch of the University of Montana's Office of Continuing Education, and we began planning the symposium for a date 2 years hence. In the spring of 1986 we asked Dan Bailey, a fire management officer on the Lolo National Forest, to chair the symposium and workshop, a task that he handled with skill and enthusiasm. The USDA Forest Service, University of Montana, and Extension Forestry were soon joined as symposium sponsors by the Society of American Foresters, National Fire Protection Association, and the Montana Department of State Lands.

While our symposium plans were in full swing, the Washington, D.C., office of the Forest Service began a national initiative on the same topic and organized meetings of more limited scope and attendance than the ones we planned. Shortly before our symposium was held, the National Fire Protection Association, in cooperation with the Forest Service and the U.S. Fire Administration, published a splendid background document called "Wildfire Strikes Home," which resulted from their conference held in Denver, CO.

Ironically, the spectacular 1987 wildfire season in the West threatened the attendance and thus the success of our symposium; but large numbers of people were able to break away from fire duty in northern California, Oregon, and elsewhere just in time, and attendance swelled to over 500. As we had hoped, this event brought together diverse groups responsible for or concerned with the protection of people and homes from wildfire in the Interior West. These included city and rural fire departments, State and Federal fire control and management personnel, State service foresters, extension agents, soil conservationists, consultant foresters, and professional tree services, land-use planners, land developers, home builders, homeowner associations, county and State officials, realtors, mortgage lenders, insurance industry professionals, and still others.

These proceedings are a compilation of symposium presentations. In some cases they are transcriptions from tape recordings, which the presenters were subsequently allowed to inspect and edit. Because of the diverse audience, the presentations are non-technical and are often conversational in style. The authors are solely responsible for content and style of their presentations.

Several dozen people contributed directly to the symposium's success through service on the program committee, as session moderators, speakers, panelists, workshop leaders and coordinators, and poster presenters. Assembling the proceedings after this complex event was a daunting task accomplished by two project secretaries, Jan Bixler and Charlene Houska.

Symposium attendees will note that the threat of wildfire to people and homes continues to grow. Several buildings were lost in a February 1988 wildfire near Whitehall, MT; 15 homes were lost outside Rapid City, SD, in July 1988; and last-minute fuel reduction measures were applied to save multimillion dollar facilities at Old Faithful and Grant Village in Yellowstone National Park. Sadly, many more homes will have been lost to wildfire by the time this proceedings reaches your hands. Nevertheless, implementation of the concepts, procedures, and practices contained herein, can minimize the losses of not only homes, farm buildings, and commercial structures, but also the loss of human lives.

William C. Fischer,
Stephen F. Arno,
Compilers

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FIRE MANAGEMENT IN THE WILDLAND/URBAN INTERFACE -

A CHALLENGE FOR RESEARCH AND MANAGEMENT

William T. Sommers

Forestry managers and researchers alike are being challenged by changes that are accompanying the social and demographic adjustments that the United States and many other parts of the world are experiencing as we move into post-industrial societies. Many of us enjoy the benefits of those changes and live in or near a wonderful place where we can experience the beauty of nature while enjoying the creature comforts of urban living. Those of us not fortunate enough to live in this place, probably will visit or vacation in it soon. This place is the Wildland Urban Interface.

In our modern perspective, wildlands are thought to be something for our pleasure with all danger and discomfort removed. By frequenting them, we seek to escape from the negative aspects of urban life while requiring that the full scale of positive urban living benefits be provided to us. One does not have to step back too far to realize that an inherent and self-deluding conflict is present. Since much of the wildland area of the United States is composed of public lands, Federal, State, and Local government agencies are at the focal point of this conflict. Moreover, emergency services, including fire protection, are usually the most stressed element in the wildland urban linkage. We are being challenged with new realities and new requirements that will only increase in importance in the years ahead. They are challenges we can not ignore. Some thoughts about these challenges and what we need to do to meet them follow.

Although fire in the wildland/urban interface is receiving increased attention at the local, state, and national level, there is little information on the magnitude or significance of the problem. Available information is fragmented, incomplete, and difficult to aggregate on a national scale. Further, data are inadequate to project trends or analyze cause and effect relationships. Without such data and analyses, fire managers, the public, legislators, developers, and others involved with fire in the wildand/urban interface are unable to assess the situation, make informed decisions, or plan for the future at local, state, and national levels. Therefore, we need to define, describe and quantify the wildland/urban interface from a fire management perspective. We need to determine the spatial and temporal distribution and trends of fire-related attributes of the wildland/urban interface.

Perhaps the most critical knowledge deficiencies with wildland/urban interface fire problems are those involving the behavioral sciences. Fire managers lack the fundamental knowledge about interface residents necessary for sound program planning. Furthermore, managers need to know how to work effectively with local governing bodies in implementing fire safety and risk-reduction programs. Finally, incentives that affect the behavior of all actors in the interface must be understood before effective program planning and implementation can occur.

Analyses of the fire environment (fuels, weather, fire behavior) resulting in fire risk and hazard within the wildland/urban interface need to be made. We lack knowledge on changes in the natural fuel complex resulting from anthropogenic stresses. We lack knowledge on the physics and expected behavior of fires within the wildland/urban environment.

There is a lack of information concerning community and structural design procedures to reduce the fire threat to the wildland/urban interface. We need models for evaluating fire risks for community designs and plans. We lack methods of evaluating fire risks for individual structures and sites. We need improved fire-resistant construction materials and systems.

Wildfire and prescribed fire in the wildland/urban interface have potential to cause residual impacts on the urban environment, either by causing changes in ecosystem properties that affect future fire hazard/intensity or by creating direct, offsite impacts such as air pollution/smoke or sedimentation. We need to better understand responses of vegetation to fuel hazard reduction techniques that might be used in the wildland/urban interface. Effects of such treatments on the structure and composition of recovering vegetation may significantly alter fire hazard and risk in these areas. And, we need to better understand the effects of fire on soil erosion, sedimentation, water quality, and flooding which can cause substantial property damage, environmental impacts -- and even loss of life -- in developed areas of the wildland/urban interface.

Mr. Sommers was invited to prepare this paper as a foreword to these proceedings.

William T. Sommers is Director, Forest Fire and Atmospheric Sciences Research, U.S. Department of Agriculture, Forest Service, Washington, DC.

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Assessment of fire hazard in the wildland/urban interface is necessary to assist landowners, fire managers, and regulating organizations in efforts to minimize losses of life and property due to wildfire. The topic of fire hazard is considered here to emphasize elements of flammability and difficulty of suppression of structures, vegetation, and other fuels in the urban/wildland interface, and does not include risk of ignition or values of urban improvements.

We lack reliable criteria to develop effective fuel and vegetation management guides to protect homes from wildfire damage in wildland/urban interface areas. Existing hazard reduction guides for forest areas are mostly based on rather subjective assessments of hazard. The reliability of such guides over the full range of conditions that exist in forest residential areas is not sufficiently known.

What are the most cost effective strategies and tactics for wildland/urban interface fires? The effectiveness (including limits) of most suppression activities -- in terms of fire behavior, fuels, and application variables -- have not been quantified in terms necessary to allow the tradeoffs of different suppression alternatives to be determined and an optimization process applied.

There are no well-defined methods for evaluating the costs and benefits of hazard modification on (a) homesites, (b) neighborhoods, or (c) adjacent flammable vegetation. Each of these levels of resolution present different opportunities for reducing losses in wildland/urban fires and have different decision maker needs. Informed allocation of financial resources by any of these groups of decision makers is very difficult without a well-displayed integration of estimated costs and predicted losses.

SESSION 1--KEYNOTE

Laurence E. Lassen, Moderator
Director, Intermountain Research Station
Forest Service, U.S. Department of Agriculture
Ogden, Utah

THE CHALLENGE OF PROTECTING PEOPLE AND HOMES FROM WILDFIRE IN THE INTERIOR WEST

Honorable Norman Bangerter
Governor of Utah

Thank you very much and good morning. I'm glad to see that firefighters get up and go to work in the morning like everybody ought to. It is a pleasure to be here in Missoula and in the state of my good friend Ted Schwinden. I appreciate his invitation to be with you this morning along with yours. I've enjoyed Ted Schwinden for many, many years and he's a great fellow and I'm sorry to see that he has decided not to run again, but I can understand why. Some days the fires get hot even in the Governor's office.

In accepting this invitation I wondered what I could do as a Governor to contribute to this symposium. At first, I felt like I don't really have any experience fighting those fires, and what could I tell those of you who have for many, many years. What would I tell you that you don't already know. But as I thought more about it, I realized that maybe I have more in common with you than the eye would first see. After all, as Governor, it seems like half my time is spent putting out fires and the other half is trying to light a fire under some staff member or department head, legislator or the public in order to accomplish the challenges that we have. As Governor, you are always aware of the risk of things getting too hot to handle or of getting burned.

There is another reason why it is appropriate for me to be here. I was in a scheduling meeting last Friday afternoon when I was interrupted by a phone call from Wasatch County, which is about 40 miles to the east of Salt Lake City. It happens to be the place where I have a summer home. The call was from the owner and developer of that property. He asked if I could arrange for a tanker to protect my home. There was a fire burning not too far from there and he was getting a little nervous and thought that I might be able to use my influence. Needless to say, I was interested all at once, and sent my security people out to get more information, called the Forest Service and others in the area about what the challenges were and how threatened we were. I called one of my sons and said, "Are you in a position that if I call you, you could go to the mountain and at least get our mementos out of our home up there in case the fire gets too close?" Well, within a couple of hours they called back and said they felt they had the situation under control and to my knowledge, my summer home is still intact. I hope that that is the case. But it is something that we all think about as we go through the challenges of where we build, how we build, and what we build.

Most of my life, as indicated, has been spent in building and land development. And as a result, much of my life has been devoted to taking a piece of ground and turning it into a subdivision--a place where people can live and will reside. As the population of the West grows, there's a growing need for housing, for new subdivisions, and new communities. That is a fact of life. One natural consequence, however, is that people end up living in areas that were once either under agricultural use or, in your terms and mine, were wild country. Sometimes, there is a tendency for people to assume when they leave cities for the more rural or suburban settings, that they still have the same kind of fire protection. The fact is, however, a home built on the edge of a forest is going to face different fire risks than a home in the center of the city. And if yours is in a place like mine, it probably doesn't have the kind of fire protection and water system that we have in the cities in the volumes that could make the difference. So some of those systems are also weak as well.

The risk of wildfires, to not only wildlife but to human life and property, are apparent to all of you. A check of recent history demonstrates the damage that has occurred from fires. For instance, in 1985 wildland fires resulted in the loss of 1,400 homes, 3 million acres, and 44 lives--both civilians and firefighters. In 1986, 13,500 people were evacuated from areas threatened by wildfires, and 3 firefighters lost their lives. The 1987 wildland fire season isn't over yet, although hopefully the worst of it is over. Already, two fires in California have destroyed some 65 homes. Just one month ago, more than 500,000 acres of forest land had burned in California, Idaho, and Oregon. During a two-week period, more than 20,000 people were involved in

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Keynote Address presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Honorable Norman Bangerter is Governor of Utah and Chairman of the Western Governors Conference, Salt Lake City, UT.

fighting wildfires. Undoubtedly, some of you here today participated in those emergency actions.

Although Utah land was not involved in the worst of the September range fires, our rural community of Oak City has almost been burned over by wildfire three times in the last seven years. Several other communities in Utah, including Grantsville, Gosham, and Alberta have also been seriously threatened. Within the past few weeks, a grass fire in the foothills above a fashionable Salt Lake City neighborhood caused us some concern. Fortunately, it was brought under control before any homes were seriously threatened.

The risk to wildlife and the environment from wildfires is also very self-evident. The risk to human life and property is also very real.

What can we do about these risks? Appropriate action can be taken in three areas. And I might add that with the challenges that every government entity is facing, with budget crunches, and that's from the federal government to local governments where probably most of you are involved, we still have to make sure we keep our priorities straight in protecting the infrastructure that is so important to all of us. So the three things that I think we can do are:

1. Assess and evaluate the risks of fire. And this shouldn't be done after something is built. This should be done before something is approved and allowed to go forward.

2. We can increase education to enhance prevention. And that's something that's needed in every home in America. We've had, in Utah, not just for the areas that are at greater risk but for all of our citizens, an education program where we've tried to encourage every family to make an evacuation plan for their individual home. We had an instance in one of our small communities last year where a family gave credit to their son for having brought home that fire plan idea and, them having sat down and made one, for saving the lives of some of those children and saving many of their precious possessions.

3. We should emphasize training and coordination of firefighting efforts. And that's where all of you come in, in a very real way.

I'd like to take a moment to discuss each of these areas. First, we should attempt to better understand the physics of fire behavior. The development of systems to assess and manage fire hazards in areas once unpopulated, now residential, could help firefighters be more effective in fighting those blazes. The mixture of structures, vegetation, fuel properties, and moisture relationships are not always well understood. This is particularly true in areas only recently developed. The better you know what you're dealing with, obviously, the more successful you are going to be.

Second, better education can enhance fire prevention. Property owners, local governments, as well as recreational land users, need to have a better understanding up front of the threat of wildfires and how to minimize fire risks. In some instances, fire safety ordinances or building codes may be inadequate. And I emphasize that. As a developer, I was always challenging those and you will continue to be challenged by the developer because the tendency is that 'we want to build something and we don't want too much interference'. We have to make sure that that is balanced. Fire ordinances for an established urban area may not be adequate for a newly developed residential section, particularly on the edge of a forest or in a forest, as I happen to be. For instance, it may be prudent to prohibit the use of highly flammable roof materials in high fire hazard areas. We have a lot of propane tanks in the area that I'm in and of course, they can be very hazardous as well. It has been said that ignorance is bliss; in this case, it may be fatal. Part of the education process is for fire protection agencies to come up with rational solutions rather than unreasonable impediments. That's the balance that we talk about when we talk about developers and planners and regulators reaching that accommodation which is so necessary for the general safety of our people. A few dollars invested in prevention efforts may save lives, millions of dollars spent in fighting fires, and millions of dollars in property loss. And I might add, millions of dollars in insurance premiums.

The third area that we need to constantly address involves the training of firefighters and coordination of firefighting efforts. As more homes are built in these marginal areas, the complexity of firefighting continues to increase. As you know, these fires and structural fires are simply not the same. Methods designed to extinguish a residential fire are not effective against the power of a wildfire. As residential areas spread into formerly unpopulated wildlands, the need for training increases. I suspect that few wildland fire suppression personnel are adept at fighting structural fires. Nor are most municipal fire departments trained or equipped for wildfires. Specialized training may help assure adequate responses to wildfires on the fringe of residential development.

I mentioned earlier that during a two-week period last month more than 20,000 people were engaged in fighting western fires. This is part of a great cooperative effort among firefighting agencies across the nation. Utah committed much of our supervisory force and sent two trained crews of state prison inmates to the fires. At one point, our forestry division had personnel in Hawaii, Idaho, California, and Oregon. Fortunately, no significant fires occurred in Utah while our people were in other states. Agreements already in place among the western states, as well as a variety of agreements with the federal government, facilitate this kind of cooperation. The importance of cooperation with each other cannot be overemphasized.

Nationally, the Forest Service, National Fire Protection Association, United States Fire

Administration, and National Association of State Foresters have combined efforts to address the problems of wildfires in residential development. As a western governor, I want you to know that I support and appreciate those efforts. For our part, Utah will continue to cooperate with other states and contribute to controlling and preventing these fires. I'm confident that other western governors feel the same as I do--that we simply must work together in order to effectively deal with this threat. I commend each of you for your efforts individually and collectively as you deal with the challenges we face in protecting our public lands as well as our private property. And I, as with you, may have the same interest, that it's not only someone else's property, but it's sometimes our own.

Thank you very much for allowing me to be with you, and I hope you will have a very successful conference and come to some real conclusions as to what we can do to enhance our efforts in this area.

A NATIONAL CRISIS

Anthony R. O'Neill

ABSTRACT: The problem is clear: As more people throughout the nation move from urban areas to more rural settings they are exposing their homes and their families to highly combustible environments -- environments not equipped with urban or even suburban municipal infrastructures necessary to protect these newcomers. The result of this migration has been tragically clear: wildfires which heretofore posed a threat to wildlands alone, are now taking lives and property. Yet, with programs which lead to heightened public awareness and education, home owners, business and governmental leaders and the fire service can effectively meet this growing problem head on. Although a level of national attention is necessary, solutions must be achieved at the state and local level and their success will come through a multi-disciplinary approach.

INTRODUCTION

Senator Melcher, distinguished guests, members and colleagues; it seems only yesterday when one and a half years ago I had the pleasure of welcoming several of you to the National Fire Protection Association ... where we held a Task Force Meeting to identify strategies for getting involved in combatting the fire problem of the wildland/urban interface. Remember, this was in the wake of one of the most severe wildland fire seasons in the history of the nation.....1985, when 83,000 wildland fires burned 3 million acres, destroyed or damaged 1,400 dwellings and killed 44 civilians and fire fighters. Something had to be done!

At that meeting in April, our small group of 20 experts hit the ground running. We made tremendous progress brainstorming ways that we could harness the many talents available to us in the United States. Just a few months later, the next generation of over 100 leaders met in Denver.

I'm sure most of you have had a chance to see the fruits of those intense meetings -- The "Wildfire Strikes Home" report. In it, the strategies for seeking solutions to this problem are clear: a united effort -- not just on a national basis, but regional and local as well -- must be developed, drawing attention to the problem and implementing solutions. By the end of that conference in Denver, we knew the next step in this initiative would be to gather on a regional basis ... to bring together various multiple disciplines ... to plan and develop strategies, and programs that will work -- because each and everyone of us has a stake in seeing results.

And all of this because we are interested in preserving and protecting what we have -- our families, our homes, our landscape and our natural environment. As we go about the business of preserving and protecting what we have, we intuitively focus our efforts on three steps. First, we generally acknowledge that there's a problem and then we try to define it. Secondly, we agree on strategies to solve that problem. And third, we find a way to implement those strategies. This week, we're somewhere in between step 2 and step 3 -- at the leading edge of change, and we're 500 strong! How quickly the number of committed individuals and organizations has grown. And how encouraging that growth is to all of us at the National Fire Protection Association. But a word of caution .... We must not fall into the trap of only "preaching to the choir" .... we must reach out beyond our own numbers .... and this conference represents that new beginning; we congratulate Dan Bailey and his conference committee for a very broad based participation.

OVERVIEW - National Fire Protection Association

Like the organizations many of you represent, NFPA has always had a commitment to protect man and his environment from fire mainly in the built environment. Certainly, through the publication and distribution of the National Fire Codes, as well as our training and public firesafety education efforts, our member dedication is clear. With more than 40,000 members, and the thousands who serve on technical committees, our Board of Directors and the hundreds of thousands who carry our fire prevention messages deserve the bulk of the credit.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Anthony R. O'Neill, Vice President, National Fire Protection Association, Quincy, MA.

Each and every day our members work to help, encourage, and bring together the people who must apply firesafety information. And this is where NFPA's activities most closely parallel what we're in Missoula to accomplish. For here, we're writing a new chapter in the history of cooperation between the public and private sector, federal, state and local governments in the critical matter of protecting our families, our homes and our lands from destructive fire. And it's even more than that -- like the diversity which brings success to our efforts, this initiative must include not just representatives from the fire services. It must involve architects, engineers, bankers, insurers, builders, developers, schools and families ... to name a few. We see it in everything we do at NFPA, and wildland fires are no exception.

SETTING THE STAGE

I'm not going to take too much of your time this morning talking specifics about the wildland/urban fire problem. However, let me recap some of this year's highlights. Back in March, along with Al West and Clyde Bragdon, I participated in a press conference in Washington on this problem. Back then the press had a "ho-hum" attitude because not much was happening.

Since then, the devastation in the United States has been growing at an incredible rate.

- o Nearly 300 structures had been destroyed earlier this summer - including the fires in Pebble Beach, Spokane, and Lake Tahoe
- o Thousands evacuated from their homes in Alabama, Virginia, Pennsylvania, California, Nevada, Idaho, Oregon, Washington, Colorado, Minnesota, and Arkansas
- o And, by summer's end the property loss value had exceeded 35 million dollars...not to mention the unprecedented costs incurred in fighting these fires.
- o In the first week of September, close to a million acres were burning in California, Oregon, Idaho, and Washington severely taxing all of the forest fire fighting forces up and down the west coast.

Let's also take a look at what's been happening outside of the United States.

- o Many European nations have suffered terrible wildfire losses over the past couple of years.
- o Wildland/urban fire continues to be a major problem in Australia.
- o But who among us can forget the photographs from China earlier this year showing the worst conflagration of 1987 .... an accurate accounting may never surface as village upon village fell to walls of flame raging out of control over millions of acres. Thousands were left homeless when the fire consumed one entire town of 25,000 in 20 minutes. The problem surrounds the globe -- it is everywhere.

WHAT CAN WE DO?

So what can we do? First, we must grasp the great extent of the problem and understand that virtually no region of this continent is exempt from this threat. Next, we must develop strategies and solutions.

This morning you heard from leaders who expressed their concerns, and you have heard their appeals for help. This afternoon you will begin hearing from the troops - each with areas of expertise which can effect change.

This week we'll hear about the reality of politics, insurance, and fire protection planning. Throughout the next few days those discussions will delve even further into the intricacies of uniting many different interests - each with their own agenda. The issues will be tough, but they'll help us as we endeavor to apply what we learn here .... back home.

Issues such as turf battles, private enterprise, and homeowner desires are real and can have a decided impact on whether or not community fire protection intitiatives work. Harnessing the support of those who can make a difference like builders, developers, and the media is critical, for they may heavily influence whether or not people even believe the problem exists.

Let me address the media for a moment. When wildfire strikes whether in forests, structures or both - it is spectacular. Its awesome power over everything in its path is overwhelming...and, it makes for great "press."

Right or wrong, people do believe what reporters tell them. So when they show up at a fire, we should be prepared to work with them - this is a prime opportunity to point out the problem and to recommend solutions. Readers or viewers have their interest piqued - it's time to strike. Make sure your media have good information. In a few words, they can spread a message which gets the attention of developers who might have ignored the problem, the city councilor who has refused to believe there is a problem, and the homeowner who still feels the beauty of shake shingle roofs far outweighs their threat of fire.

Multi-Disciplinary Approaches Are Successful

Once you've started breaking down barriers, you can begin bringing together the decision makers in your community. I've talked about who some of those people might be and am sure you can think of others. The important thing is to include everyone, tying together those with a common interest every step of the way.

For instance, in discussing planning, have the fire services represented along with the city planner, developers, architects and local insurance agents and mortgage bankers. If a new development in a high fire risk area is poorly designed or, because of inadequate roads or water supply, or because it is inaccessible to fire protection services, the development becomes less likely to be financed, and, perhaps, more costly to insure.

Earlier I talked about the NATIONAL FIRE CODES. Written by committees of volunteers, these codes represent what these people each of whom has an interest in the issue from a little different angle - feel will be an acceptable firesafe approach to a design or use. The process - from start to finish - allows for public comment and discussion.

It has been our experience in the built environment that once you get all your leaders focusing in a similar way - allowing for debate and discussion - you will see progress. It's exciting and, more importantly, this progress can mean the saving of lives and property.

NFPA's Continued Commitment

As you all are doing great things at a local or regional level, let me assure you that those of us who are involved at a national level will continue our national focus and our support to you, as well.

The Association I represent here today is committed to the importance of this initiative in all respects: through its publications, its committees, and its membership. Specifically here are some of our recent initiatives:

- The theme of this coming November's NFPA Fall Meeting in Portland, Oregon,

with many sessions picking up angles of the Intitiative pertinent to their membership;

- The "Wildfire Strikes Home!" newsletter, sponsored by partners in the Initiative, has been and will continue to be published and distributed by NFPA to tens of thousands, and
- I'm pleased to report that the NFPA Board of Directors has approved the addition of a Wildland Fire Management Membership Section of the Association. Through this section those existing and prospective NFPA members with a keen interest in this important area of firesafety may come together to share experiences and continue the initiative.
- Our monthly FIRE COMMAND magazine now features a regular column titled "Wildland Fire Management" authored by your Conference Chairman Dan Bailey.

But beyond these latest initiatives ... beyond our committees, beyond what we publish ... I'm here to tell you today, on behalf of the NFPA Board of Directors, as well as the NFPA staff, as well as our 40,000 members worldwide, that the NFPA is deeply committed to doing whatever is necessary to help you ... to help our nation ... solve the urban/wildland interface fire problem.

I've been to many meetings, I've spoken to many groups, and I've been part of many initiatives, but I think that what we will do over the next few days is no less than an historic occasion.

Today, we begin writing a new chapter in the history of cooperation between the public and private sector and among federal, state, and local governments.

We will begin writing this chapter in history, because we have finally come to the realization that fire respects no jurisdictional boundaries ... and because our families and homes are too important to us not to try to seek innovative alliances in our lifesaving efforts.

Looking at the roster of those assembled here ... and the zeal and commitment that I see in each of you ... I'm confident of our ability to succeed in this effort. After all, what better week to rededicate ourselves than this, National Fire Prevention Week. Let's never forget that 116 years ago, this week, the Peshtigo, Wisconsin, wildland fire killed over 1,500 people ..... and yet it was the great Chicago fire that everyone associates with Fire Prevention Week.

Good luck in your symposium and workshop deliberations.

WILDFIRE STRIKES HOME

Al West

This is a significant and vitally important conference. The issues to be discussed are real and there is a critical need to meet the challenges these issues present. We are facing a fire protection crisis of major proportion in the United States.

Since the last week of August, 15,000 people have had to flee their homes; 7 fire fighters have died; and 19 families have lost their homes. Approximately 22,000 fire fighters from Federal, State, and local fire and resource agencies were mobilized to fight some 1,600 fires that blackened about 750,000 acres of land in California and Oregon. Natural resource losses will reach into the tens of millions of dollars. Some 3 billion board feet of timber have been destroyed or seriously damaged. The cost to the taxpayers in this country will exceed $100 million.

A significant factor in this fire situation was the protection of life and property. Fire fighting resources dispatched to protect natural resources had to be diverted for this purpose. This was an obvious and proper decision, but the price in terms of natural resource losses and fire fighting costs was extremely high.

Was it necessary to sacrifice watersheds, the economic livelihood of many communities, the natural beauty, wildlife habitat, and tree growing capability of the land for years to come? If there was no alternative, the answer would be a non-debatable yes. But there is an alternative and that is why you are here. You are the key to reducing the growing losses of life, property, and resources to wildfire.

At the moment, our focus is on the West, but this is very definitely a national problem. This year we have recorded property loss and fatalities from wildfires in 10 states, from the east coast to the Pacific. Most of these losses resulted from relatively small fires, not from major newsmaking conflagrations. The citizen deaths came primarily from debris fires that escaped control, entrapping the people who were trying to stop them.

Since 1985, when the national wildland-urban wildfire protection initiative began, the losses from wildfires have generated sobering statistics. In just 3 years, some 2,000 structures (mostly homes) have been damaged or destroyed, nearly 100 lives have been lost, several thousand fire fighters and citizens have been injured, almost 16,000 square miles have been burned, and the cost for firefighting, property damage and natural resources destroyed will exceed $2 billion.

We have no way of estimating the emotional impact on people who lost family, friends, or personal possessions. How do you place a monetary value on family heirlooms or the emotional impact of a family life shattered by death or the terror of fire? During the recent fires in California many people suffered emotional trauma from the doomsday atmosphere created by the smoke pall hanging over their homes for days. Often the human impact is forgotten when considering wildfire costs.

Neither can the loss of natural resources be minimized. The replacement of soil, vegetation, and scenic beauty could take as long as a century. Our Nation's natural resources are not without limits. When resources burn, we mortgage our children's future. Major wildfires often devastate local economies through the loss of timber supplies or the degradation of scenic beauty. Land planned for homesite development often becomes unsaleable because of the ravages of fire.

We can never completely eliminate the destruction of fire, but it is within our power to reduce the human suffering, economic cost, and damage to natural resources. We have the technology, the management skills, and intellect necessary to dramatically reduce wildfire destruction. The critical catalyst needed is your commitment.

Wildfire does not have to strike home. Homes in the interface do not have to burn and we do not have to continue to sacrifice our natural resources to protect them. People can live fire-safe in the wildlands. We can build fire resistant structures, landscape to reduce fire hazards, and modify wildland fuels to reduce fire intensity. Necessary fire fighting facilities and improvements can be provided.

People living in the wildland/urban interface area can take responsibility for some of their own fire protection. Aggressive and effective fire prevention programs can be developed. More emphasis can be placed on increasing the cooperation between wildland and structural fire agencies. Local governments should be encouraged to develop needed fire codes and regulations. We can involve the builders, planners, architects,

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Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Allan J. West is Deputy Chief, Forest Service, Washington Office.

educators, insurance professionals, and other community leaders in our problem solving efforts.

As Bill Rhatican, Senior Vice President of the Advertising Council, commented: "The Wildfire Strikes Home Initiative is an excellent effort because the focus is a problem that can be solved. Unlike so many problems today that go beyond the capability of the individual citizen, this is an issue where a person can make a difference. Each individual can have a definite influence on personal and community well being."

Your challenge is to take full advantage of the opportunity to develop your abilities and return to your communities as leaders and catalysts for cooperative action that will prevent "Wildfire from Striking Home."

DEALING WITH THE WILDLAND RESIDENTIAL FIRE PROBLEM:

A POLITICAL PERSPECTIVE

Honorable Peter DeFazio
U.S. House of Representatives

Good morning from Washington DC. I caught the end of Senator Melcher's remarks and thought that I might try a little different perspective because I've got a little different background than the Senator in coming to Congress. I've dealt with some of the problems you are dealing with in that I was a County Commissioner before I came to the Congress. And I've dealt with some attempts at solutions to the urban and wildfire interface.

We have, in Oregon where I come from, a comprehensive land use plan for the entire state, and I had the distinct privilege of chairing the Lane County Board of Commissioners as we worked through a comprehensive plan for the rural areas of Lane County. Lane County is about the size of the state of Connecticut, and we have the Willammette National Forest, and the Suislaw Forest and other extensive timber holdings, both private and Bureau of Land Management. So we spent a great deal of time on the question of whether or not homes could be constructed in timber lands, and we actually developed some fairly restrictive rules, particularly in industrial lands. And secondly, to what standards those homes should be constructed, dealing with fire breaks and other issues. So, in a way, we've dealt with some of the things that are confronting you. The interesting thing is that the problem presented to us was not the problem which I've seen in southwestern Oregon over the last few weeks; that is, of the diversion of resources from fighting the naturally-caused wildfires. But the problem presented to us back then was the need to restrict dwelling construction because these dwellings would be the immediate cause of fires. And that did happen in one fire in Oregon this summer, the Bland Mountain Fire, a pretty large fire. But all of our other major forest fires, including the ones that are still going on, were naturally caused, lightning caused, and we had to deal with the problem which you are gathered together to deal with, which is how to deal with the interface. How are we going to deal with limited resources in fighting these sorts of fires which involve both homes and wildland resources?

I don't think it is an issue that the federal government is ever going to deal with directly. It is going to be dealt with at the local level, the county level, the state level, in terms of building construction standards, zoning requirements, and fire breaks, that sort of thing. Those are not things the federal government, except in encouraging education, or through the cooperative fire programs, training, and other things, will ever deal with. I don't believe that we should attempt any sort of national zoning standards.

Right now in my district, we have a good example of the problem we're dealing with. There is a large fire still out of control in the southwestern part of my district. It's called the Silver Complex fire and it is burning in timber land both within and outside a wilderness. There was no one on that fire for almost 10 days. When we had the lightning storm come through, we had so many strikes, we had so many fires, that we had to divert all the resources away from the timber lands to deal with the immediate threat to life and private property. So the decision was made that that fire would be let run. I think that had we been able to get people on it sooner, we could have stopped it--there were a number of opportunities on ridgelines and other natural barriers to stop it. The fire burned into areas that were tougher to deal with and now they're putting lines around 100,000 acres. The result is a tremendous loss of timber value and a tremendous loss of watershed value. And the questions is, if we hadn't had such a conflict in other areas of the state, if we didn't have to divert so many people to protecting homes in forest areas, could that fire have been contained sooner? And I think the answer is yes. Now, that presents a tremendous public policy problem. I'm not about to sit here and say we should let people's homes burn or we should endanger people's lives. That's not the solution. The solution involves the preventative issues that you're dealing with, and I'm looking forward to reading the results of your conference, and hope that you give us some guidance. What do you need from the policy makers in Washington? I know one thing is you need a little more certainty in the federal commitment to this issue. We don't need to threaten cuts every

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Address presented via satellite from Washington, DC at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Peter DeFazio is a member of the U.S. House of Representatives from the state of Oregon, Washington, DC.

year in the cooperative firefighting budgets, which this administration has done. And I certainly will oppose those efforts.

Next week in the Public Lands Committee, (Parks and Public Lands), on the House side, of which I am a member, we are going to hold hearings and do oversight on the fires that occurred in Oregon and northern California and discuss both the ongoing efforts, because it's still very dry and very hot and we still do have fires out of control and posing a continuing threat. We'll discuss the immediate mitigation that needs to go on or the attempts at mitigation before the winter rains hit us. We're going to talk about salvage and reforestation. I intend to introduce the issue of prevention and discuss that a bit and what role, if any, the federal government could have played in those areas.

There's one other thing that is unique perhaps to Oregon, and I'm sure there are some Oregonians there. We did invoke sort of a dusty statute called the conflagration act. The governor was able to invoke that by proclamation in declaring a state of emergency. That allowed the governor to mandate that all the fire departments, the urban fire departments and the rural fire departments around the state, be required to contribute to the forest firefighting effort. I think moving in that direction is a way to deal with the structural problem, to perhaps revisit that statute and make it a little more explicit and perhaps have the federal government or the state get more involved in training of those urban crews. That would result in a large pool of people available to deal with the structural problem so that we don't have to divert as many resources of our trained wildland firefighters to the protection of structures. That is something that warrants a little further review.

I would be happy to take questions and answer them if I can.

Q: What do you feel is our next step to implementing a statewide wildland interface education program?

A: Well, I think one way, perhaps of dealing with this, and it's something that I'm going to discuss with the governor, is the use of National Guard troops. Some people say, well, you can't train up the National Guard every year in the expectation of having a bad fire year and having them ready to go as a trained backup. The same thing in dealing with the urban interface, with the homes and other structures in our forested areas, I tell you, as a County Commissioner, it's pretty tough to enforce the fire breaks and other things that were required in the plan. Yes, we can see when the homes are originally constructed, that the proper standards are used on the new construction in terms of nonflammable materials, that the fire breaks are originally constructed, and that people don't landscape in a way to encourage the fire or threat to their dwelling. But over time, we can't send people back on an annual basis--I don't know of any county in America that is well enough funded to do that--to check on how the fire breaks are doing, whether or not they've modified some part of the structure, or maybe even put on a roof without a permit or something else that would change a roof.

I think we need to concentrate on the years when we know we're going to have a problem. We knew we were going to have a problem this year, and I think the counties and the state need to gear up sort of a contingency program for educating the people who live out there. If you do it every year and it's sort of ongoing, you're going to have people react negatively--"I'm being harassed by the people from down at the County Court House again." But if your approach is "We expect there to be forest fires this summer, we've got a real problem coming up--we've got very low moisture content"--and then gear up for an education effort, for an enforcement effort during that year, both voluntary and involuntary, I think that would be a way to go, and it would be a way to better use the resources. And so, what I would suggest is that we need to gear up for those years, the drought contingency plans for the years when we know we're going to have a problem.

Q: My understanding is that the Senate/House joint appropriations committee recently queried whether federal wildfire suppression forces have decreased since 1980. I would appreciate hearing your findings if they are available.

A: OK. Well, you're referring to the Senate side. My understanding is that there have been significant cuts, that's only in perspective as a new member on the House side, and I'll be getting into the details of that next week. I think these are easily characterized as penny-wise pound-foolish cuts. If we save a million dollars by cutting out a prevention program, the damage in my district alone is 100 to 200 or more times that in loss of just the timber resources, let alone getting into the other natural resources we've lost. We're going to have huge problems with our fishery. So it's a place where the federal government just can't afford to skimp. I will advocate putting as many resources as can be used productively into that program.

Q: Would you support authorization of the Forest Service to train for the protection of structures on or near Forest Service property?

A: As I understood the question, it was if the federal government would provide funds to assist in training for prevention and/or fighting of fires to protect structures that are adjacent to or in forested areas. I think that should be part of the cooperative program. The problem we deal with, as people continue to build in those areas, is how large will that get, how large will the problem get. And if people are knowingly building in hazard areas now, the question is should they essentially be subsidized by the federal government. That's a tough call. I think that in my county where we had problems with water quality, we notified people, "if you build in that area, you may not have a water supply in the future--there's a potential for problem." I think we should notify people in the same way who are building in fire hazard areas or potential fire hazard areas. "Potential fire hazard exists in this area; you don't have an urban fire department here. We're going to do our best to protect you, but first of all you've got to build the structure in conformity with the standards, you need to maintain these sorts of fire breaks, and we will attempt to train you and your neighbors, volunteers, the rural fire departments, or whatever, in prevention techniques." But when it comes down to fighting fire, we get back to that tough problem--you're probably not going to say to someone, "We're going to let your house burn because we're going to protect that stand of timber over there." That's something that I don't think anyone is willing to say.

Q: You commented that the federal government would probably not be directly involved in urban wildfire development policies. Why not? The development within the flood plain areas are in some ways governed by federally mandated insurance programs.

A: Well, I think the person who asked that question has probably never been a County Commissioner. The question, if the audience couldn't hear it, is why won't the federal government be involved in some sort of national zoning or development standards plan for people building in potential wildfire areas. I don't see it as a federal responsibility. Zoning is traditionally reserved to local governments, with or without direction from the state. I don't think there's any way we could adopt, given the complexities of local areas, a national standard that would fit. You have very different problems in grassland, prairie brush areas than you do in forested areas, or even in different forested areas--ones in southern California, northern California versus the forests in the northern part of my district, or the pine forests out in eastern Oregon. It would be a very, very complex set of standards and I think it is best left to local control, but we've just got to make sure that these efforts are undertaken at the local level, with or without state direction or state incentives or state funding.

Q: Where does, in your mind, a fire protection agency's responsibility end and the public's responsibility begin? Should a fire protection agency spell out its limitations to the public?

A: OK. When the fires are burning, it's really hard to say. I mean, I'm so close to this issue right now, still having problems in my district and having gone through a bad fire season. Where does the public responsibility end or begin, or the individual responsibility, is a really tough question. Like I say, I think we need to concentrate our efforts on the years when we know there's going to be a problem, because if you go back to someone five years in a row and you've got them taking out brush or whatever, the enforcement becomes so expensive, and in fact quite troublesome. I'll relate a story. I own a small tree farm and one of my neighbors had built without a building permit, and the county officials kept coming back to bother the person and say that he didn't have a building permit, and the last time the fellow came by, he took out his 30-30 and said, 'this is my building permit.' Now, the unfortunate thing is two years later the guy's house burned down--it may have been problems in the construction. But there's a resistance to that sort of regulation in our rural areas, so I think concentrating our efforts on the years when we know there's going to be a problem, getting more voluntary compliance, and then doing whatever mandatory requirements we can during those years, will pay a bonus. But on a year-in year-out basis it's a really tough problem to say that 'you, the individual, have the responsibility to do this.' People are away, home ownership changes. You have to keep educating people, you have to keep pushing them. Possibly some sort of notification when houses change hands, notice that you're buying or moving into or building in a wildfire hazard area.

Back to the other question, too, about federal control in the flood areas. It's been a very, very lengthy process and problem. And the only reason that the federal government is exerting that control in those areas is because we have a federal flood insurance program. We don't have a federal fire, wildfire insurance program. And again, that would be where I don't see the federal government getting involved.

Q: Can there be a tax break for people who make their homes more fireproof, such as getting rid of a shake roof, cutting a fire break, etc? As I understand, home improvements such as this makes the tax go up. If a tax break was given, it might give people a reason to fireproof their homes.

A: OK. Of course, the reason the taxes generally go up is because of the improvements and property tax assessments. But I think looking at federal incentives is a good idea because if we can get the people in an area to build their homes firesafe, so we don't have to divert resources, then, again, we are going to save tremendous amounts of timber and other wildlands resources, and the federal government is going to come out far ahead, plus maybe even saving on firefighting costs. So, I think that that's an interesting proposal and definitely something to be looked at and I'd also encourage local jurisdictions and states who are charged with firefighting responsibilities to review their taxation in thos areas.

Q: Should the federal government provide incentives to state and local governments to develop interagency cooperation for fire suppression?. If so, what would be the nature of these incentives?

A: Definitely. In California, the state provide equipment to rural fire districts, and they can use that equipment year-in year-out. The obligation is, when there's a call from the state when there is an emergency, they have to go. I would look at something along those same lines, i terms of either the federal or state government working with the local agencies--a program that provides either discounted equipment, perhaps bought through the federal procurement process where there's purchasing in large volumes so you can get it at a cheaper price, direct federal subsidies in some areas, or grant programs. I think any of those would work and just put basically the same proviso on them. If you accept this equipment, you are obligated when we need you, when we have a major wildfire problem, to come. And if we are dealing with urban fire departments, who are trained mostly in structural fires, they would be providing the protection on the structures while other people are working on the wildfire itself. There might also be an obligation for training that goes along with that, to say that, well, if you are going to accept this equipment and you are going to be obligated to come and help in future emergencies, you've also got to keep trained to a certain standard so that you will be more useful to us on the firelines.

Q: Which agency should have responsibility for such a program?

My suggestion would be to encourage the program and whatever agency is appropriate in a local jurisdiction or within a state, whether its vested in a state department of forestry or whether its vested in some other part of the state government or local government. Our governmental structures are so different throughout the West; the same is true in the East, where there is a similar problem, but it is not as apparent this year. Again, there are very different governmental structures. So its hard to detail which one is most appropriate.

Well, my summary would be, give us some ideas. I'm not an expert--you're the experts. It's apparent to me that we have a very real and growing problem, particularly in my region of the West, and I'd like to hear your suggestions. Send them to me, send them to the Public Lands Committee. Be heard. Don't just go to the conference and go home. Be heard and be proactive in your counties, be proactive with your state, and the next year we have a bad fire season, let's be ready.

SESSION 2

William E. Perrin, Moderator
President, Montana First State Bank
Stevensville, Montana

POLITICAL CONSTRAINTS AND OPPORTUNITIES IN WILDFIRE RESIDENTIAL AREAS

Ken Cassutt

My name is Ken Cassutt. I am an Assistant Attorney General with the New Mexico Attorney General's Consumer Protection and Economic Crimes Division. My responsibilities with the Attorney General include enforcement of the New Mexico Subdivision Act, Sections 47-6-1, et seq. NMSA 1978 throughout the State. I spend approximately 80 percent of my time in the subdivision enforcement area.

The views expressed in this presentation are my own and do not represent the point of view, official or otherwise, of current New Mexico Attorney General Hal Stratton. I hope that limitation will not detract from what I have to say.

I have, in a sense, come to this Conference through the back door. I spend very little of my time dealing with fire protection issues. My technical knowledge is deficient. The main thrust of my job is to address past violations of law, in effect reacting to past problems. Unfortunately, this leaves little time to lobby for changes in the law which may prevent future problems.

I have also found fire protection to be a political issue, especially in a state like New Mexico which is trying to grow on a shoestring. The Attorney General's role is to enforce the law with impartiality. Because there are so many laws being broken in so many ways, it is necessary for an Attorney General to set priorities, decide where his time and his staff's time should most appropriately be spent. But this duty to enforce the law impartially to a certain extent resists the politicization of the Office, and makes it troublesome for an Attorney General to be involved in political issues.

It may, nevertheless, be helpful for me to relate what small effort I have made, as an Assistant Attorney General, to encourage counties in New Mexico to pay attention to wildfire hazards in subdivisions. The point of this story may very well be that state government can play a role in educating local governments, developers, and potential purchasers about fire protection issues. Once that education is complete, however, the political tug of war must be played out over the local mud hole.

First, some background on New Mexico's subdivision laws. There are currently 33 counties in New Mexico. Under the Subdivision Act, each county has adopted regulations which govern the approval and sale of subdivisions within that county. While the Subdivision Act sets forth some minimum requirements for subdivisions of a certain size or density, and specifies certain issues which each county's regulations must address with respect to all subdivisions, the counties have wide discretion in determining the types and stringency of requirements they impose upon subdividers. This discretion creates opportunities at the local level at the same time that it permits stagnation.

The issues which a county's subdivision regulations must address do not include fire protection. The Subdivision Act requires regulations dealing with the quality and quantity of water, liquid and solid waste disposal, terrain management and adequate disclosures, among other issues. For most subdivisions, the subdivider's proposals on these subjects must be reviewed by state agencies with expertise in those areas. But there is no specific mention in the Subdivision Act of wildfire hazards, nor is there any prescribed role for the State Forestry Service, in the review of subdivision proposals, even for subdivisions planned for heavily wooded areas.

One of my first tasks as an Assistant Attorney General, in late 1985, was to help convince the boards of commissioners of the various counties throughout New Mexico that it was imperative for them to pay attention to wildfire hazards in subdivisions. This task was suggested by the Council of the Adelante Resource Conservation and Development Area, which encompasses Colfax, Mora and San Miguel Counties in northeastern New Mexico, and includes the easternmost range of the Sangre de Cristo Mountains. I attended a meeting of the Council Board at which two excellent members of our State Forestry Service, Ray Polosky and Frank Smith, gave a bone-chilling slide presentation illustrating the lack of precautions taken against wildfire in New Mexico's woodland subdivisions. I was hooked.

The Council's official request of the Attorney General's Office was that we advise their three counties of each board's legal responsibility to

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Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Ken Cassutt is Assistant Attorney General of New Mexico, Santa Fe, NM.

deal with wildfire hazards and, more impressively, of the potential for liability if the board ignored the problem. We were covering new legal ground. As stated previously, the Subdivision Act does not specifically require the counties to promulgate fire protection regulations. Moreover, county commissioners are generally exempt from liability for negligence under the New Mexico Tort Claims Act in connection with decisions made within the scope of their duties as public officials (Section 42-1-4 NMSA 1978). Between the lack of specificity in the Subdivision Act and the remnants of sovereign immunity, we weren't left with much of a hammer.

After consulting with then Attorney General Paul Bardacke, we sent out a general "newsletter" to all 33 counties, rather than picking on the three northeastern counties, which made several suggestions for improving subdivision regulations, including adding fire protection features. In this letter, we cited a general requirement in the Subdivision Act that counties adopt regulations pertaining to "any other matter relating to subdivisions which the board...feels is necessary to ensure that development is well planned, giving consideration to population density in the area" (Section 47-6-9(A)(11), NMSA 1978). We believed that provision at least provides a justification, if not an absolute mandate, for fire protection regulations. We also suggested in the letter that a clever lawyer representing a family injured or killed in a wildfire may seek to bring the county, or the commissioners themselves, in as defendants. Such a claim could be based, not on a theory of negligence, but on a violation of the commissioners' statutory duty under the Subdivision Act to ensure that development is "well planned." A claim under the Subdivision Act would not be subject to immunity. We therefore toed the line on some legal issues, and in giving the counties an honest analysis, left them with the impression that wildfire was an issue which deserved their attention.

During the following year, a few counties actually adopted subdivision regulations dealing with wildfire hazards. Anita Miller, a dynamic lady who was my predecessor in this position, took hold of guidelines prepared by the State Forestry Service and, with the assistance of Frank Smith, forged new wildfire hazard regulations for Rio Arriba County. Similar regulations drafted by Anita were recently passed by Grant County. The regulations in these counties will be put into play only after the State Forestry Service has, after study, identified areas of these counties in which the risk of wildfire is significant.

Despite these successes, several other counties, in updating their subdivision regulations, have resisted including special requirements for wildfire hazard areas. Our office did not press the issue with these counties, but I wondered what lay behind their resistance. After proposing revisions to the Subdivision Act in advance of the 1987 legislative session, I discovered just how political an issue increased regulation is in New Mexico.

My legislative proposals on the wildfire issue appeared to me to be simple and sensible. All counties would be required by the Subdivision Act to adopt regulations specifically dealing with "designated wildfire hazard areas." Adequate ingress to, and egress from, each parcel would be required at a minimum. Other measures would be within the counties' discretion, so long as the problem of wildfire was addressed. Proposed regulations would be reviewed and commented upon publicly by the State Forestry Service. In addition, any subdivision of more than 24 lots proposed within a wildfire hazard area would have to be reviewed by the State Forestry Service for compliance with the county's new regulations.

I aired my proposals before all interested parties. The Realtors' Association of New Mexico, which speaks for the land development industry on legislative issues in our state, immediately protested. We were trying to add another layer of unnecessary regulation to the approval process for rural subdivisions, they cried. The new regulations would drive up the price of land, making it even more difficult for the poorer people of our state to own their own homes. The entire state could be designated a wildfire hazard area. Why vest authority in a state agency which is not directly accountable to the people? The state would try to impose requirements in the midst of a state forest which were designed for the middle of Manhattan. The only fireflow standards which a rural subdivider could afford to meet would be useless in fighting a typical rural blaze.

The realtors announced that if the wildfire provisions were kept, they would kill the bill. Based on past history, we knew they were fully capable of doing so. We compromised by keeping the ingress-egress provisions. The rest of the proposals were deleted from the bill presented to the legislature.

New Mexico is a relatively poor state. In many rural areas of our state, if land is not sold cheaply, it does not sell. Since there is an irresistible urge to subdivide, this often means that quality and safety are sacrificed to affordability. In most parts of our state, market principles are more firmly entrenched than the fear of wildfire.

There are people in state government as well as the private sector in New Mexico who will continue to push past political stumbling blocks to achieve a reasonable regulatory solution. I cannot represent that I will be one of those people. I hope I may continue to play some role. But it is those on more intimate terms with the play of politics--our elected officials at the state and local levels--who must be recruited by the participants in this Conference. Just as the obstacles are political, the ways to overcome those obstacles must be found in the political arena.

Thank you very much for inviting me here and allowing me to express my views.

HOW ARE INSURANCE PREMIUMS FOR HOMES LOCATED IN WILDLAND AREAS DEVELOPED

Jerry A. Foster

ABSTRACT: Advisory residential fire rates are developed by the application of either the Personal Lines Manual or the Homeowners Manual, both published by Insurance Services Offices, Inc. (ISO). Major areas of consideration are the following:

1. Construction; where the obvious benefits of fire resistive construction over lesser types, such as frame, become evident.
2. Private Protection is reviewed. Some of the items considered for rate credit are:
   . residential sprinkler protection
   . signaling systems (i.e. heat or smoke detectors)
3. Public Protection; the level of public fire protection is measured by the application of the Fire Suppression Rating Schedule (FSRS). The schedule measures that adequacy of both the local fire department and water supply features. Distances to the fire department and water supply is a major consideration.
4. Actuarial and statistical information; calculation of premium loss ratios.

All of these, and more, are considered in developing an advisory residential fire rate in wildland areas.

INTRODUCTION

Insurance Services Office Inc. ISO is a non-profit unincorporated association of insurance companies who have pooled resources to have functions performed collectively for them; functions that each company would have to do on their own were it not for ISO. The obvious benefit is a standard product at a lower cost. ISO provides statistical, actuarial, policy form printing and distribution, and survey work for over 1200 affiliated insurance companies for 16 lines of insurance. Some of the common lines of insurance are liability, automobile, boiler and machinery, homeowners, farm and commercial fire. Prior to the formation of ISO in the early 70's all these functions, for the various lines of insurance, were performed by different organizations in different states. Needless to say there were few common conditions or concepts that existed across state lines, or between lines of insurance.

ISO is not an organization concerned with only one line of insurance, such as fire, in one state or in a group of states; but rather an organization concerned with all common lines of insurance in all states. The significance being that ISO is a total insurance rating organization, and is finding and correcting redundancies, misconceptions and overkills that previously existed. Such improvements have been possible only under a countrywide operation like ISO.

FIRE PROTECTION

The public fire protection that most everyone sees and hears everyday, is the obvious--a fire engine responding to an alarm. This aspect of fire protection is all that many people are ever exposed to and, therefore, is the only relationship they see between fire protection and insurance. However, the truth of the matter is, that once the fire department has been called, there is generally already a loss because something is burning and something is being destroyed. The role that the public fire services do play at that point, however, is to minimize that loss once it has started.

ISO is not in the business of grading public protection, its in the business of developing individual property relativities. The only reason for being at all interested in public protection is to reflect recognition for effective public protection in the individual property rate. Public protection does make a difference in the extent or percentage of loss to value that can be expected in a given fire situation. The tool used to measure public protection is a Municipal Grading Schedule.

The municipal Grading Schedule used by ISO and its predecessor organizations was composite of benchmarks or standards, as some have referred to them, with which the conditions found in a community were compared.

The original versions of the Grading Schedule were not developed by ISO, nor any other rating organization, but rather was developed by an insurance trade association known as the National

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Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Jerry A. Foster, P.E., Director, Classifications, ISO Commercial Risk Services, Inc., Parsippany, NJ.

Board of Fire Underwriters. The stated purpose of the National Board was significantly different than ISO's and other rating organizations. Their purpose was to review municipal fire protection with the objective to influence the community leaders to improve the fire protection being provided. The Grading Schedule was a tool to quantify all of the various fire protection related services that a community provided. The National Board dealt only on a community-wide level and did not get involved in individual properties; therefore, each item they reviewed was only reflected in the Public Protection Classification (PPC).

The state rating bureaus, on the other hand, started with a review of the individual building. It was their job to develop individual property fire rate relativities. Because it was commonly agreed that, with all other variables being equal, properties located in areas with better grades of municipal fire protection should have lower rates, the rating bureaus, as a matter of convenience, used the classifications developed by the NBFU's Grading Schedule.

DEVELOPMENT OF FIRE RATES

ISO is not here with a new story; but rather a new chapter in the old story - relating insurance operations to the fire service. For the first time since the formation of ISO as a major insurance rating organization the various bits and pieces used to develop fire insurance rates are being put in their proper perspective. ISO was asked to discuss only one of those pieces. "How are insurance premiums for homes located in wildland areas developed".

Let us review the rating variables for residential fire insurance which may assist in a better understanding when we discuss the specifics associated with the public protection Municipal Grading Schedule.

Advisory fire rates are published in the Personal Lines Manual and the Homeowners Manual. The manuals are maintained and published by ISO. The following are the variables for consideration in developing a residential fire rate:

1. Public Protection Classification developed by the application of the Municipal Grading Schedule.
2. Distances from a responding fire department and water supply.
3. Construction (frame, masonry joisted or fire resistive).
4. Private Protection; this considers the potential credits for internal protection like sprinkler protection and detectors.
5. Actuarial and Statistical Analysis; the base rate associated to the public protection classification is adjusted based on local and state premium loss ratios.

To the series of charges and credits ISO has mentioned so far, a modification is made for the public fire suppression available in the vicinity of the individual property.

The basic questions being addressed by the incorporation of the public protection classification variable are; what can we expect at this specific location when all of the designed systems in the dwelling fail, and a fire occurs? Can we expect a total loss, or will the loss be minimized by manual fire suppression?

FIRE SUPPRESSION RATING SCHEDULE (FSRS)

In determining the level of loss, a public protection Municipal Grading Schedule is used, titled, "Fire Suppression Rating Schedule (FSRS)". The FSRS produces 10 different public protection classifications with Class 1 receiving the most rate recognition and Class 10 receiving no recognition. Class 9 indicates there is a responding fire department meeting the minimum criteria as outlined in the FSRS. Class 1-8 indicate there is both a fire department and water supply meeting the minimum criteria as outlined in the FSRS.

The FSRS simply defines differing levels of public fire suppression capabilities which are credited in the individual property fire insurance rate.

The schedule contains 14 major items which are used to analyze the fire protection in each and every municipality rated. Credit is given for each item in which compliance is met for the needed conditions. Adding the credits assigned to all items determines the fire protection classification of the municipality. The FSRS is a performance schedule which measures those capabilities of the city which the city themselves control.

With today's high cost of living, to manage and to operate a fire department, the city normally will design their fire defense needs around the average conditions expected.

The FSRS now recognizes this by dividing the schedule into two sections. The first section analyses the average public fire suppression, the second section looks at the few larger individual properties. Neither section one or section two considers sprinklered buildings in the determination of needed fire flow for the city.

The FSRS establishes a needed fire flow in gallons per minute for suppression of a fire in a building; all properties which exceed a needed fire flow of 3500 gpm will be separated so not to influence the evaluation of the city's public protection class. Fire protection responsibilities will now be shifted from the city government to individual property owners. Built-in sprinkler systems, smoke detectors, upgrading construction and other internal fire protection improvements will now become more of an incentive to property owners.

Previous schedules measured such technical elements as reliabilities of the water supply, valve spacing, emergency provisions and other engineering specifications. The FSRS will give recognition to water availability when that availability is ensured. Cities which can provide the needed water for the appropriate time will find that water-hauling systems or large hose lines will receive the same credit as would a fixed underground water distribution system.

In the past, ISO's grading standards overemphasized such things as heavy equipment, personnel and water supply and underemphasized preventive measures. There was often a low correlation between a city's ISO rating and its actual fire losses.

Changes in the ISO standards now shift this emphasis in general. The new standards emphasize actuarial losses or rates based on actual fire loss history in urban centers and do provide more flexibility in rural areas.

These changes will have a significant impact on city fire safety planning. For the first time cities have an incentive to review their entire fire protection system. These new standards will encourage cities to search for cost-effective means to prevent, suppress and investigate fires.

The public fire protection class is only one of a number of factors that affects insurance rates as already mentioned. Further, in most cases, the other factors generally have a greater effect on insurance rates than the public protection class. If these observations are considered together with the fact that the rates on class-rate properties, which include dwellings, do not change with every change in public protection class, the conclusion is reached that it generally is not possible to justify the cost necessary to produce an improvement in public protection class by the resulting savings in insurance premiums.

We are finding that the larger and better equipped cities that grade as 2nd, 3rd or 4th class, do not necessarily show any dramatic reduction in insurance losses for the smaller residential properties, even though these better classes do cope more satisfactorily with the larger industrial, shopping center or business-block fires. For this reason, the dwelling and homeowners insurance rates in many states, do not show any insurance savings as the public classification improves.

One explanation may be that a fire in a frame dwelling may not require multiple companies and a mass of equipment if the department is alerted promptly, if it gets to the fire soon enough and if the men are well trained for this responsibility.

City officials frequently ask ISO if the savings in insurance premiums that would result from an advance from one public protection class to the next better one would be sufficient to justify the cost of the improvements necessary to produce the change in class. If this were the case, public protection improvements could be justified on an economic basis, and all cities would be class one. This is not the case.

The function of ISO is to evaluate the suppression capabilities actually provided, within the scope of its limited responsibility. The FSRS is the tool ISO uses to accomplish this function.

ISO considers it their responsibility to give to city officials the information they need to understand the insurance classification and the factors that affect it. It is the city's prerogative to make its own decision based upon whatever it believes it relevant to that decision.

THE FEDERAL GOVERNMENT'S ROLE IN MAJOR DISASTERS: AN OVERVIEW OF NATIONAL, STATE AND LOCAL GOVERNMENT RELATIONSHIPS

Gregg Chappell

ABSTRACT: Presentation on the Role of the Federal Government in Major Disasters: an Overview of National, State and Local Relationships to the Symposium and Workshop on Protecting Homes from Wildfire in the Interior West at Missoula, Montana.

INTRODUCTION

This presentation will address the role of the Federal government in major disasters, and the Federal, State and local relationships involved. However, let us first review how the Federal disaster assistance program fits into the overall role and functions of the Federal Emergency Management Agency (FEMA). The Agency (fig. 1) was established by the President in Reorganization Plan Number 3 in 1978 and involved the consolidation of a number of Federal agencies into a single agency with a wide range of responsibilities for emergency planning, preparedness, response and recovery, and hazard mitigation. FEMA includes the Federal Insurance Administration (FIA) and the US Fire Administration (USFA), the latter also participating in the symposium/workshop. FEMA also includes ten Regional Offices, with boundaries following the standard Federal Regional organization (fig. 2), which administer FEMA programs with the States including the Disaster Relief Program. In administering disaster relief, the FEMA Regional Offices work closely with the State Office of Emergency Services and the designated Governor's Authorized Representative.

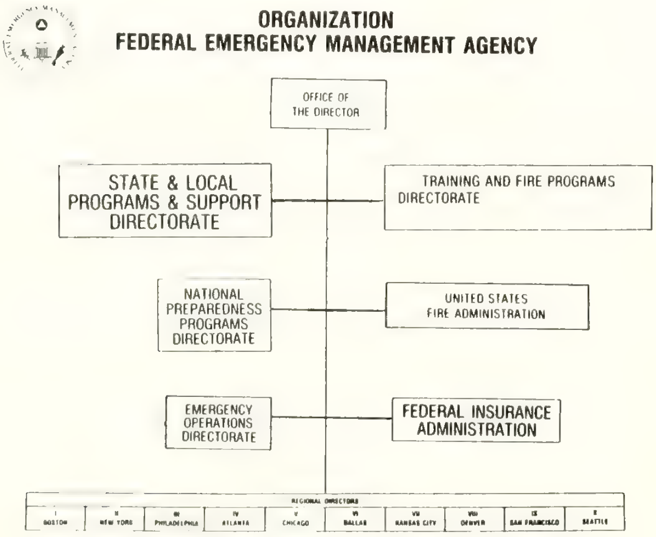
ORGANIZATION
FEDERAL EMERGENCY MANAGEMENT AGENCY
OFFICE OF THE DIRECTOR
STATE & LOCAL PROGRAMS & SUPPORT DIRECTORATE
TRAINING AND FIRE PROGRAMS DIRECTORATE
NATIONAL PREPAREDNESS PROGRAMS DIRECTORATE
UNITED STATES FIRE ADMINISTRATION
EMERGENCY OPERATIONS DIRECTORATE
FEDERAL INSURANCE ADMINISTRATION
REGIONAL DIRECTORS
I BOSTON
II NEW YORK
III PHILADELPHIA
IV ATLANTA
V CHICAGO
VI DALLAS
VII KANSAS CITY
VIII DENVER
IX SAN FRANCISCO
X SEATTLE

Figure 1—FEMA Organization

DISASTER RELIEF ACT

The Disaster Relief Act of 1974, Public Law 93-288, provides Federal financial assistance for improving state disaster preparedness, and supplementary Federal assistance for individuals as well as state and local governments and certain private non-profit organizations to assist them in recovering from the devastating effects of major disasters. Under Executive Order 12148 the President has delegated this authority to FEMA. The Disaster Relief Act is administered by the Office of Disaster Assistance Programs which is a component of the State and Local Programs and Support Directorate. FEMA promotes an "all hazards" approach in its comprehensive emergency management and we stress the integration of hazard mitigation in providing Federal disaster assistanc

It should be noted that all Federal disaster assistance always is supplementary to the efforts of State and local governments. It should also be emphasized that hazard insurance coverage by

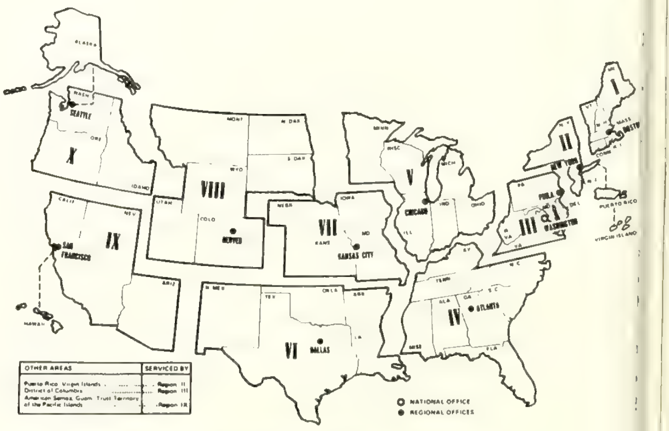

Figure 2—FEMA Regional Boundaries

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Robert G. Chappell, Chief, Public Assistance Division, Office of Disaster Assistance Programs, Federal Emergency Management Agency, Washington, D.C.

individuals and State and local governments further reduces the need for Federal disaster assistance. In this regard, another component of FEMA, the Federal Insurance Administration, administers the National Flood Insurance Program which makes available both subsidized and actuarial insurance to participating flood-prone communities. In addition, disaster assistance may be available from other Federal agencies under their own statutory authorities following disasters, either with or without a Presidential declaration. These include the Small Business Administration (SBA), the Farmers Home Administration (FmHA), the Corps of Engineers (COE), the Federal Highway Administration (FHWA), and others.

A "major disaster" is defined in the Disaster Relief Act of 1974, Public Law 93-288, as any "hurricane, tornado, storm, flood, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, drought, fire, explosion, or other catastrophe in any part of the United States which, in the determination of the President, causes damage of sufficient severity and magnitude to warrant major disaster assistance above and beyond emergency services by the Federal Government to supplement the efforts and available resources of States, local governments, and private relief organizations in alleviating the damage, loss, hardship or suffering caused by a disaster."

Since enactment of the first disaster relief legislation in 1950 there have been some 800 major disasters declared by the President. The vast majority were a result of flooding although there were a lesser number declared for tornadoes, earthquakes, and other catastrophes. During this period there were thirteen fires including the Chelsea, Massachusetts, urban fire in 1973, the Lynn, Massachusetts, urban fire in 1981, and several California wildfires affecting urban property occurring in 1980 and 1985. A summary of the types of major disaster declarations since the enactment of the current legislation in 1974 is shown in table 1.

The Disaster Relief Act also authorizes assistance under Presidentially declared emergencies. Such assistance normally is limited to meet the specific need for which the emergency was declared. In addition, FEMA has a small program under Section 417 of the Disaster Relief Act which authorizes assistance for States for the suppression of forest and grassland fires which threaten to become major disasters.

Table 1--Major Disaster Summary
(April 1974-March 1987)

NUMBER OF DISASTERS DECLARED BY PRESIDENT 367
TOTAL AMOUNT OF FEDERAL FUNDING ....$3.1 Billion
TYPES OF DISASTER:

	TOTAL	FLOODING	NON-FLOODING
SEVERE STORMS AND FLOODING	228	228	0
TORNADOES	77	33	44
HURRICANE / TYPHOON	33	33	0
SNOW AND ICE	12	0	12
EARTHQUAKE / VOLCANO	6	0	6
FIRE	6	0	6
DROUGHT	5	0	5
TOTAL	367	294	73

DISASTER PREPAREDNESS

States have a vital role in preparing for disasters and emergencies. FEMA is authorized to make grants not to exceed 50 percentum of the cost of improving, maintaining, and updating State disaster plans but are limited to $25,000 per annum. Such assistance is made under the Disaster Preparedness Improvement Grant Program and shared costs are funded under a Comprehensive Cooperative Agreement.

STATE REQUEST

When a disaster threatens or occurs, local authorities take immediate steps to warn and evacuate citizens, alleviate suffering, and protect life and property. If additional help is needed, the Governor may direct execution of the State emergency plan, use State Police, or National Guardsmen, or commit other State resources as the situation demands. If the Governor determines that the disaster is of such severity and magnitude that effective response is beyond the capabilities of the State and affected local governments and that supplemental Federal assistance is necessary he may request a major disaster. The request is processed through the FEMA Regional Office in which the State is located, a Federal damage assessment is made, and the request is forwarded to Headquarters, FEMA, in Washington, D.C., which submits a recommendation to the White House (fig. 3).

DAMAGE ASSESSMENT

Evaluating the Governor's request for a major disaster is an important step in the declaration

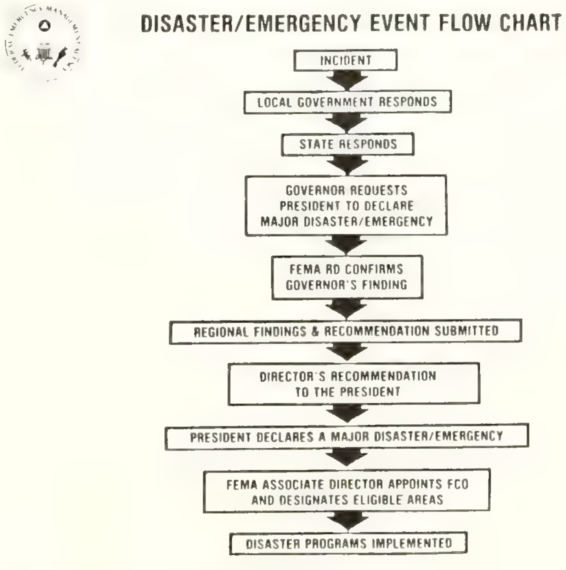
DISASTER/EMERGENCY EVENT FLOW CHART
INCIDENT
LOCAL GOVERNMENT RESPONDS
STATE RESPONDS
GOVERNOR REQUESTS PRESIDENT TO DECLARE MAJOR DISASTER/EMERGENCY
FEMA RD CONFIRMS GOVERNOR'S FINDING
REGIONAL FINDINGS & RECOMMENDATION SUBMITTED
DIRECTOR'S RECOMMENDATION TO THE PRESIDENT
PRESIDENT DECLARES A MAJOR DISASTER/EMERGENCY
FEMA ASSOCIATE DIRECTOR APPOINTS FCO AND DESIGNATES ELIGIBLE AREAS
DISASTER PROGRAMS IMPLEMENTED

Figure 3—Disaster Event Flow Chart

process and the Preliminary Damage Assessment (PDA) is performed at the FEMA Regional level. It normally includes field surveys of the disaster affected areas identified in the Governor's request and usually is accomplished on a county-by-county basis by FEMA Regional personnel and representatives of other Federal agencies concerned. This may involve door-to-door surveys and include a fly-over of the affected area. Representatives from the State are also involved.

The PDA provides documentation to support the determination that the incident is beyond the capabilities of the State and affected local governments and also provides management information which is used in the Federal response after a declaration. Items which are addressed during a PDA include a determination as to the extent of insurance coverage and probable recovery, the existence of unmet individual needs resulting from the disaster, the potential eligibility of disaster damage for Federal program assistance, and the impact of the disaster on individuals and communities within the disaster area.

FEDERAL RESPONSE

Upon a Presidential declaration of a major disaster, FEMA designates areas (usually counties) eligible for Federal disaster assistance, appoints a Federal Coordinating Officer (FCO) to coordinate the Federal response, and establishes one or more disaster field offices to process applications for assistance from individuals, and from state and local governments and eligible private non-profit organizations, with disaster-related needs. These are referred to, respectively, as Individual Assistance and Public Assistance. Federal disaster assistance is provided pursuant to a FEMA-State Agreement which states the understandings, commitments, and conditions under which the assistance is provided.

INDIVIDUAL ASSISTANCE

A Presidential declaration of a major disaster makes a broad range of assistance available to individual disaster victims. Temporary Housing Assistance is available up to 12 months for individuals and families whose homes are uninhabitable until alternate housing becomes available. Options include a minimal repair program, the provision of rental housing or defaulted government-owned housing, and direct payments for temporary housing. Disaster Unemployment Assistance and job placement service is available for individuals who become unemployed as a result of the disaster. Individual and Family Grants (IFGs) up to $5,000 may be provided to meet disaster-related necessary expenses and serious needs resulting from the disaster. IFG costs normally are cost-shared on a 75 percent Federal-25 percent State basis. Other assistance includes the distribution of food coupons, the provision of legal services, and the availability of crisis counseling to eligible disaster victims. In addition, the Small Business Administration (SBA) and Farmers Home Administration (FmHA) can provide low interest loans to individuals, businesses, and farmers for the repair or replacement of damaged real and personal property which was not covered by insurance.

Individuals requesting assistance normally are processed through Disaster Application Centers staffed by Federal agency representatives who process applications for benefits. This process has been automated extensively to expedite the assistance and to preclude a duplication of benefits among the Federal programs. However, one-on-one contact with disaster victims is most important in order to properly assess their needs and determine counseling requirements. In addition, individual assistance also is provided by private relief organizations such as the American Red Cross, Salvation Army, Mennonite Disaster Services, and other private relief agencies.

PUBLIC ASSISTANCE

Under a Presidentially declared major disaster FEMA can provide Federal financial assistance for the clearance of debris from public or private lands or waters, for emergency protective measures for the preservation of life and property, and for the repair or replacement of public and eligible private non-profit facilities which were damaged or destroyed by a major disaster. Public Assistance normally consists of the reimbursement of eligible program expenses, although in unusual circumstances FEMA has the authority to direct other Federal agencies to provide assistance which is beyond the capabilities of the State and affected local governments. Facilities eligible for assistance under the Act include streets, roads, and bridges, water control facilities, buildings and related equipment, and public and certain private non-profit utilities. Such assistance is cost shared on a 75 percent Federal-25 percent State and local basis.

State and local applicants for assistance normally attend local Applicant Briefings immediately following the declaration during which the public assistance program and application process is explained. Teams of Federal and State inspectors, accompanied by a local representative, survey the damage and prepare Damage Survey Reports (DSRs) which are the basis for a Project Application (PA) for Federal disaster assistance. Following FEMA's approval of the application, interim funding is provided under a Letter of Credit and final payment is made after the work is completed, including any required final inspections and audit. The Public Assistance Program is automated to include the DSR, PA, and funding process.

As in the case of many Federal programs involving the construction of facilities there are a number of special considerations which must be addressed. For facilities located in areas susceptible to flooding a floodplain management review is required under Executive Order 11988 and 11990. The Coastal Barrier Resources Act prohibits most Federal assistance on designated undeveloped coastal barrier areas. An environmental assessment may be required where the facility is substantially changed or where a new facility is built. Flood insurance may be required under the Flood Disaster Protection Act for Federal financial assistance for insurable structures located in flood-prone areas. And, under the insurance provisions of the Disaster Relief Act, general hazard insurance may be required as a condition for the Federal grant to protect against the hazard for which the declaration was made to the extent that such insurance is reasonably available, adequate and necessary.

MITIGATION ASSISTANCE

Section 406 of the Disaster Relief Act provides that as a condition of any grant or loan made under the provisions of the Act, the State or local government shall agree that the natural hazards in the area in which the proceeds of the grants or loans are to be used shall be evaluated and appropriate action shall be taken to mitigate such hazards, including safe land-use and construction practices. FEMA has been placing increased emphasis on this provision and requires the submission of State hazard mitigation plans in conjunction with all Federal disaster assistance under the Act including assistance as a result of urban fires.

As a recent example, following the major disaster declared for the State of California on July 18, 1985 as a result of urban damage from wildland fires, FEMA Region IX worked closely with the California Office of Emergency Services, the affected local jurisdictions, and other Federal agencies in developing a Fire Hazard Mitigation Plan. The plan identified the risks and hazards contributing to and resulting from the disastrous

Table 2--Fire Suppression Assistance Program

FIRE SUPPRESSION ASSISTANCE GRANTS (PL 93-288, 91-606, 91-79)

Fiscal Year	Program Authority	State Requests	Determination Denied	Determination Approved	Grant Amount ($000)	States Assisted
1970	91-79	1	0	1	$ 713	AK
1971	91-606	4	0	4	1,112	AK, OK, WA
1972	"	0	0	0	0	--
1973	"	1	0	1	48	AK
1974	"	11	2	9	1,096	MT, NM, OR
1975	93-288	3	2	1	77	SD
1976	"	8	1	7	1,304	MN, SD
1977	"	15	9	6	3,731	CA, ID, ME MN, MT, NM
1978	"	5	3	2	203	CO, OR
1979	"	12	5	7	766	ID, MT, NV OR, WA
1980	"	6	4	2	3	CO, WI
1981	"	8	5	3	560	NV, OR
1982	"	1	1	0	0	--
1983	"	2	0	2	94	HI, NV
1984	"	4	0	4	4,916	OR, MT
1985	"	19	10	9	1,778	FL, CA, SD WA
1986	"	3	2	1	146	NC
		103	44	59	16,555	

urban and wildfires, and specified achievable short-term and long-term hazard mitigation actions to be taken by responsible Federal, State, and local agencies.

FIRE SUPPRESSION ASSISTANCE

As mentioned earlier, FEMA also has a small program under Section 417 of the Disaster Relief Act which is separate and distinct from the major disaster provisions of the Act. It results from legislation enacted in 1969 which authorizes assistance including grants, equipment, and supplies, to any State for the suppression of any fire on publicly (non-Federal) or privately owned forest or grassland which threatens such destruction as would constitute a major disaster. Since this program was started in 1970, there have been 103 State requests for assistance of which 59 were approved for a total of $16.6 million (table 2).

Requests for assistance require close coordination between the State Forester and the State Office of Emergency Services. Each request is processed by the FEMA Regional Office which obtains a recommendation from its Principal Advisor in the US Forest Service or the Bureau of Land Management, as appropriate. Following a decision by Headquarters, FEMA, assistance over a pre-determined State floor cost is cost shared on a 70 percent Federal- 30 percent State basis. The fire suppression assistance process is shown in figure 4. FEMA has been working closely with the US Forest Service, Fire and Aviation Management, in improving the program, and also working with the Bureau of Land Management, Fire and Aviation Management, in processing State requests from Alaska.

CONCLUSION

The foregoing presentation provides an overview of the role of the Federal government in major disasters, and the Federal, State and local government relationships involved. It should be noted that Federal disaster assistance always is supplementary to the disaster relief efforts of the affected State and local governments, and is limited to specific programs authorized by the Congress to assist individual and governmental needs not covered by insurance. Relating to the theme of Protecting Home from Wildfire in the Interior West it is recognized that there are important lessons to be learned from past experience with disasters and submit that increased emphasis on the mitigation of both natural and man-made hazards can reduce future losses especially in an era of declining resources. Public education and awareness are keys to successful efforts to mitigate the susceptibility of all natural hazards.

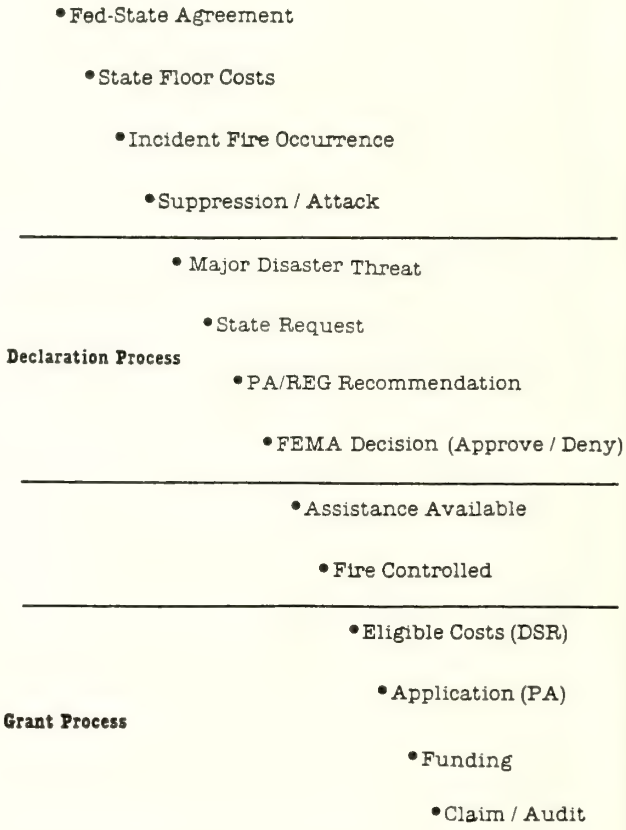

Figure 4—Fire Suppression Assistance Process

FIRE PROTECTION PLANNING IN WILDLAND RESIDENTIAL AREAS:
CONSTRAINTS AND OPPORTUNITIES FOR LOCAL GOVERNMENTS - A PANEL DISCUSSION

Peter Kenney (Panel Moderator)
Gary Tokle
Ann Mary Dussault
Rich Levengood
Gene LaBlanc
Lou Jekel
John Jackson

REMARKS BY PETER KENNEY

I think that this is a very important topic; a topic that this panel will undertake to discuss in a very comprehensive fashion, I hope. Ultimately it seems, from many of the discussions that we've already heard today, much of the responsibility for implementing any good comprehensive and effective wildland/urban interface fire protection program is going to fall on local government. There are some folks who feel that without local government's active participation in the design and implementation of fire prevention programs for these areas, it just isn't going to happen. And to a large extent that is certainly true. We have on this panel a group of people who go right across the spectrum in local government representation, and that is going to give us all a very good opportunity to hear on the one hand about the constraints and the opportunities local government face in trying to deal with this problem, as well as taking a look, on the other hand, at some successes that have been achieved. As I said we've got a broad spectrum represented on the panel. We have three county commissioners, a fire service executive, folks from state forestry, and one representative from the National Fire Protection Association (NFPA) to talk to the topic.

The communities that we represent and that we'll be talking about, run the gamut. I come from a community that you previously heard described as being a very small, rural, mountain community. We're just west of the Denver area, and we have experienced a great deal of pressure from Denver to provide residential communities - bedroom communities for commuters who work in the Denver area. My county line is 30 miles west of downtown Denver and extends to a point about 75 miles west of Denver along Interstate 70 right up to the Continental Divide. We're entirely mountainous. Our traditional, historical population centers have been in the valley bottoms, but that's no longer true. Our largest growth areas are on the slopes of mountains. We're a county where rugged individualism holds sway and where government interference in private property rights is looked upon negatively. This morning we heard Representative DeFazio describe the gentleman who responded to a building permit enforcement with a 30 caliber building permit. In many areas, that person would be considered an isolated eccentric. In certain areas of my county that's the girl next door. On the other hand, some Colorado counties have success stories to tell. One of our speakers is my adjacent county commissioner from Summit County on the west. Summit County is faced with the same types of problems as Clear Creek County. They have similar terrain and development pressures. Through community awareness and because of a different type of population, they have been able to achieve some success in dealing with the wildland/urban interface fire problem. We're going to hear several examples of such successes, and I think that's a very exciting thing to be able to talk about; not only the problems, which are many and you're all aware of them, but also some of the successes that have been achieved and that we can learn from.

Panel discussion presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Peter Kenney is Chariman, Board of Commissioners, Clear Creek County, CO.

Gary Tokle is Senior Fire Service Specialist, National Fire Protection Association, Quincy, MA.

Ann Mary Dussault is County Commissioner, Missoula, MT.

Rich Levengood is Summit County Commissioner/Consultant, Breckenridge, CO.

Gene LaBlanc is Fire Chief, Truckee Meadows Fire Department, Reno, NV.

Lou Jekel is General Counsel, Rural/Metro Corporation, Scottsdale, AZ.

John Jackson is Forest Practices Forester, Oregon Department of Forestry, Prineville, OR.

REMARKS BY GARY TOKLE

The first point I'd like to make is that homes do not have to burn in the wildland/urban interface. With the technology that is currently available, including the understanding of building materials and fuels management, we do not have to have homes that burn in the wildland/urban interface. It shouldn't be a problem. If we accept this premise, then the questions we need to ask is why does it continue to happen, and why is it happening today in areas where it hasn't happened before? In order to address the issue, there are a number of points we need to consider. Local elected officials need to play a key role in resolving this issue. Based on previous discussions among panel members prior to this presentation, I expect you will hear some interesting responses from the local government officials as to how they perceive their role. There is a real need for the local fire officials to get involved and to do things. They need to recognize the problem and they have to start doing things to try to solve the problem. State foresters and state fire marshalls, the two key fire officials in any state, need to start working together to address some of the issues. I've talked with a few state fire marshalls and a few state foresters, and the feeling I come away with is that there really isn't the cooperation and the working together to help address the issues. This situation will be solved only when those two individuals step in and assume leadership and develop needed programs to control the urban spread and to establish building requirements.

I think then that it comes back to this core of key people at the local level. There's a real necessity then, for them to work together to develop public awareness. We've talked about public awareness a lot today, you've seen it in some of the videos. We will probably hear about public awareness more from other panel members. Elected officials, particularly local elected officials, respond to what the public thinks is important. County commissioners are not going to devise regulations and rules to solve the urban/wildland interface problem unless there is public support. You can't ask these people to do that. You have to be a realist. They aren't going to be able to accomplish anything without public support. Unfortunately, if often takes a disaster to generate public support. California just passed legislation giving the state forester authority to make regulations for controlling some of the growth and problems in the urban/wildland areas. This legislation was voted on during the height of the recent fire disaster. It passed unanimously. That was a heck of a lobbying effort.

Another need is cooperation between all of the agencies and all of the emergency organizations, to develop coordinated fire prevention and fire suppression programs. Just about every fire agency has some kind of program for coordinated, mutual aid response, and fire prevention. A lot of you have such programs. They're written down somewhere. You talk about them. But when you really look at the realities of it, there's a lot of you that don't really follow through with them very well. There's a lot of talk about cooperation when we're all sitting together, and then as we walk apart, we go, "Well, to heck with those guys, we'll go ahead and do it the way we want." Really true cooperation must develop.

At the national level, there are organizations that can give you some support. The National Fire Protection Association (NFPA), the U.S. Fire Administration, and the Forest Service. Most of the wildland/urban fire problem, the homes that get burned, are not on National Forest land because people can't build homes on National Forest land. The homes that get burned are in your towns; towns that you have the control over as far as regulations and development and that type of thing. But there's a lot of help that the Forest Service gives through mutual aid in responding to assist you. They also have a lot of technical expertise. They have a lot of people that are very effective at planning and developing community plans that you can draw on to help coordinate or develop some of the programs that you want to implement at a local level. NFPA provides support through the development of standards. These standards are adopted throughout the United States and the world as codes and standards for local jurisdictions. The Forest and Rural Fire Protection Committee of the NFPA is currently developing a standard that addresses the needs of wildland/urban interface areas. Hopefully, once this is developed, you can take it and apply it locally at your level to try and accomplish the things that you need. The NFPA process can lend credibility to the derivation of local standards. It isn't just you, the local fire chief, the local emergency service officer, or whoever the person or group may be. You're starting with something that has been developed by experts and recognized nationally as a valid minimum standard.

REMARKS BY ANN MARY DUSSAULT

First of all, welcome to Montana and to Missoula County in particular. We're happy to have you. Secondly, I have a public disclosure to make. I have little or no direct experience with fires and fighting fires. But being a good politician, I have read a good deal of the literature, and I came to the conclusion that the problem we are dealing with today is certainly complex. It is obviously a multi-jurisdictional problem. It will take the efforts of political leaders, members of the public and private sectors to solve. And of course, a heavy dose of individual responsibility is required. Now again, being a good politician, what I should do is go on from there and tell you how to solve those problems. But actually, since Joe Biden sort of got kicked out of the presidential race, I don't have a lot of material to quote to you. So, what I found I had to do was resort back to my own personal experience. So, I'm going to talk to you about the legislature and the legislative role, and how it effects local government decisions in these issues.

But before I do that, I will relate to you one experience I did have with a fire in Missoula County. A couple of years ago, under a set of very, very bizarre circumstances, the mountain behind us, called Mount Sentinel, was set on fire. The fire was in August I believe, and it spread very, very quickly over the top of the mountain, and into areas behind the mountain where a number of homes are located. Our response teams worked admirably together. They worked well together, and we were very proud of them. A couple of days later, the County Commissioners decided, well, we probably better check on this, right? So we asked for Forest Service if they would fly us over the fire area. And they did that. Well, you need to understand that in Missoula County, we have three women County Commissioners, and it happens we're the first County in the history of the the country to do that. So the other two County Commissioners got to the helicopter, and for some reason, they immediately jumped in the back. And I'm sort of slow on the draw, so I jumped in next to the pilot. I went to close the door, but there wasn't one. So I looked at the pilot and I said, "Listen, I just want to tell you one thing, and you need to watch my lips very closely. You must not make a quick turn. In fact, we will do all turns at square angles, if you please." And he did it, and he was wonderful.

When I made the decision to leave the Montana State Legislature and run for County Commissioner, one of the themes that was prevalent at the time was the whole concept of the new federalism. I found it a very exciting thought that both federal and state governments would decentralize their authorities, pass them back to local jurisdictions, hopefully with a little money to follow, and that local jurisdictions, in cooperation through interlocal agreements and cooperative methodologies, would get about to solving some problems we have at the local level. Well, obviously that didn't happen. Most of the money stopped within about two years. Confusion reigned as the federal government couldn't quite figure out what it was doing with international or domestic policy. State legislatures followed suit fairly shortly in that state budgets became their primary preoccupation. And we at the local level, it seemed to me, were left with a number of problems and not a whole lot of solutions. I assume this is generally true in other States; you're going to have to just sort of generalize my comments to your own States. Since I've been a member of the Montana Legislature, I feel quite free to do a little bit of 'legislative-bashing.' Legislators tend to be extraordinarily paternalistic in their view of solutions to problems. And it's fascinating that as they deal with local governments or local jurisdictions, and I use that in the broad sense now, local governments meaning not only cities and counties, but rural fire districts and other local service districts, that legislators tend to impose a decentralized authority at the local level. And that decentralized authority can make it very difficult for those of us who work in these local jurisdictions when we view a problem, to come up with simple solutions. I mean, for example, if I were the dictator of Missoula County, and maybe someday when I grow up I will be, I would love to be able to define an issue, to bring together a group of informed, intelligent, local citizens, and come to a consensus on the solutions, and then simply impose them. Well, in a jurisdiction like Missoula County, that's simply not possible to do. Take, for example, the fact that Missoula County alone, besides having a municipal fire service in the city limits, has seven rural fire districts. Each of those seven rural fire districts have separate elected boards, and they are separate taxing jurisdictions. As a County Commissioner, I have literally no authority over those jurisdictions. That is the kind of decentralized authority that is popular in Montana, and I believe in many States in the West. Just as an example, in the State of Montana, we have something like 400 individual school districts. In the Missoula County, we have somewhere in the neighborhood of 12 to 14. A very, very decentralized form of government. I believe the legislature takes that position because that's what our constituents want. I remember being a new County Commissioner and realizing that I couldn't simply impose my will on everybody. I went up to a meeting in Seeley Lake, which is an unincorporated community north of us about 80 miles, and they were just beating the heck out of us about something or another, and I finally said, "Look, you know, I hear what you're saying and I understand the solution that you want, but you've got to understand that I don't have the authority to do that. The legislature simply has not delegated that kind of authority to County Commissioners." And I said, "I want you to know, I find that very frustrating. I would be able to do that for you. I would like to be able to do that. I would like to be able to solve that problem. But I can't." And some guy piped up from the audience and said, "Yeah, and you know what? That's exactly how we want it! We like having you frustrated. We like having control over you. And that's the way we want it."

So, legislators I believe, reflect the constituents in that view of decentralized authority. It makes it very difficult for us at the local level because what we have to do is use a lot of the mechanisms that you've already talked about, and that were just talked about, to come to solutions to problems. We simply can't impose them necessarily through the regulatory process. We must use alternate methods in order to get to those solutions.

The next thing I love about legislators is that they simply refuse to make a decision when they don't have to, and they will avoid making a decision at any cost. And having sat there for eight years, the one thing that I noticed is whenever you had a constituency that was divided, legislators loved it. If you had a coalition that came in and fell apart or a constituency that was divided and not speaking to you with a single voice, you can just say, "Look, you can't decide on what the solution is, and I can't decide on the solution. You go home and figure it out, come back in 2 years, and tell me what to do." A complete avoidance of making a decision. One of the rules of dealing with those folks is a consolidated constituency or a consolidated coalition. Such a group has extraordinary power because if a coalition speaks to a legislative group with one voice, and won't let them off the hook, the legislators have almost no option except to agree with you. It's an extraordinary phenomenon. If you've seen it work, you know what I'm talking about. It is amazing.

Let me tell you very briefly about a couple of memories that I have. I served on both the local government committees and the public health, welfare, and safety committees at different times during my career. And more often than not, constituencies came in divided. A classic example was between urban firefighters and rural firefighters. I don't ever remember talking about issues. I remember talking about turf and territory. And how "We're going to protect this turf or territory over there, but these folks here somehow want to get a piece of it." Now, I'll tell you may favorite story about that, and I won't use firefighters, I'll use psychologists. And it's true. It was about psychologists, a classic example. One group of psychologists who didn't happen to have Ph.D's came in wanting certain authorities under the law to prescribe certain kinds of treatments. Well, the Ph.D's came in and, by gum, "they couldn't do that, because these folks obviously don't have Ph.D's, and you can't let them do that because they don't know what they're going to do. And it's not going to be in the public welfare and the public's going to get hurt, and the world is going to fall apart." So we listened to this sort of parading about for two or three days. Finally, the chairman closed the testimony. There was this little, little, little, I mean tiny woman, on the committee. She'd been sitting there for three days listening to this, and she'd been chain-smoking all the time. Finally, the chairman said, "Have any of you got anything to say?" And she said, "Yeah." So he recognized her and said, "Representative Hurlaby, you have a comment?" And she said, "Yep." She said "Mr. Chairman, I've got one thing to say." She said "Thermometers have degrees, and you know where they stick that."

Another thing to remember about legislators is their agenda is probably not yours. Most people go to the legislature because they are interested in a particular subject matter, and that's what they're there for. If you look around in Missoula today, there are probably 15 different groups like this, meeting and talking about things that they have to do to get their legislators to change. But there are very few legislators that know one whit about what you're talking about here today. And we always think that what's most important to us is most important to them, and it just ain't true. So it's extraordinarily important to choose what I call a couple of winners from both sides of the aisle. To inform them, to educate them, and to bring them up to speed so that they can speak for the issues that you care about. Because, believe me, most of them don't care, and don't take that personally. It's not meant to be personal. It's just that their agenda is going to be more likely issuessuch as taxation, budgets, water, whatever it is that drove them there. And you have to capture their interest, find a spokesman, get to them, and get them to pay attention. That's an information and education process in and of itself.

Finally, as you well know, they are reactive and not proactive. It's extraordinarily difficult to get a legislative body, and this is true I believe with a legislative body like a group of Commissioners, to think proactively instead of reactively. We respond far better when there's been a problem and we can find a simple solution rather than worming our way through the complexities of trying to think how to prevent something in the future.

My advice to you is simple. 1) Pick those few winners. Inform them. Educate them. Get involved with the political process and make them your allies. 2) Develop very strong coalitions, not only among yourselves but among other entities, for example, associations of counties. The possibilities for coalitions are endless as long as you agree that you will agree on a couple of things and if you disagree on other things, it's fine. They won't fall apart. 3) Leave turfdom out of the legislative process. It doesn't get you anywhere. It simply hurts your cause, and it doesn't enhance your credibility. And 4) encourage the legislature over and over again to de-escalate the attitude of paternalism, and to delegate more and more to the local level so that folks in the local jurisdictions have the authority to make decisions to solve their own local problems. It's my belief that if we do that, we can start to change the processes that causes the horrors I read about in the literature; the horrors of fires, the horrors of homes being burned, and the horrors of people dying. And I'm going to steal a quote. For local officials, by the way, every time we have to sit and make a decision, it's like a horrible time. You've got to make a decision and 50 percent are not going to like what you did, and 50 percent are going to like what you did, so you've lost 50. I call that a horrible ending. But, in my opinion and this is the quote I'm stealing, "It's better to have a horrible ending than horrors without end."

REMARKS BY RICH LEVENGOOD

You've all heard of a yuppie. In case you don't know, a yuppie is a guy who lives in the innercity, works in a high-tech job or a financial firm, and drinks Corona beer. I'm a "marpie", and that is a "middle-aged rural professional," and that's the kind of area that I'm in. I go to a lot of wine and cheese parties, I have a pair of skis, a 4-wheel drive, and a butterfly net. That's what distinguishes me from a yuppie.

Today I'm going to concentrate on land use planning and regulations on the local level and the necessity for cooperation between units of various governmental levels, developers, and private citizens. I am going to use Summit County as a case study.

I am not a firefighter, but I certainly deal with a lot of firefighters. Today, I'm going to deal with the political process rather than fire statistics and firefighting techniques. Those are things that I don't know anything about. But I think I do know about the political process and the land use planning process.

Let me give you a little profile of Summit County. First of all, like Commissioner Dussault, we have in Summit County 7 fire districts, 6 towns, and about 20 other special districts. Let me give you a little idea what Summit County is all about. We're a recreation county. Our permanent population in 1980 was 9,000, and our peak population was about 50,000. By 1987, we had grown to 13,000, and we have around 78,000 or 80,000 estimated people on any given day in that county. By the year 2000, we'll have 20,000 permanent residents, and 124,000 or 125,000 on any given day during peak. That will be mainly in the winter. But we indeed have a summer economy also. In housing units, we've got about 16,000 housing units. Thirty-six percent of those units are owned by the primary or permanent residents, and about 64 percent are owned by second-home owners, primarily from the front range of Colorado which is approximately 2 million people. Skiing is our main industry. A third of Colorado skiers ski in Summit County - 3 million out of 9 million. We have four areas there: Breckenridge, Keystone, Copper Mountain, and Arapahoe Basin. In a just released statistic from the Census Bureau, we were among the top 5 percent in terms of population growth in the United States. Out of 3,000 counties, we ranked about 130th, I believe. Summit County is a relatively small county. Interstate highway 70 dissects it. It's about 600 square miles and about 75 percent of that, or about 290,000 acres is National Forest land managed by the Forest Service. It's heavily forested. We have one Wilderness area and development abutts both the Wilderness and other National Forest land. We have a great deal of development in those areas.

What does this profile suggest? I'm sure that this applies to many other counties in Colorado and indeed, the entire West. If you're not a ski county, you're certainly a recreation county or a second-home county, and you most certainly have federal land.

First, there's an increasing and accelerating wildland/urban interface problem in Summit County. I'm sure that's true with respect to many of your areas. Second, there is an increasing and accelerating and indeed urgent challenge to all levels of government in Summit County to get their act together. The Forest Service, for example, manages 75 percent of the land. They fight fires. They're a multiple use agency. The State Forest Service helps local governments in planning for prevention of wildfire. Local fire districts concentrate on structures, but they are certainly concerned with wildland fires. County and city planning commissions are where your land use regulation and approval lies, so they've certainly got a challenge themselves. Locally elected Boards and City Councils; however, must set the political stage for the acceptance of regulations with respect to the wildfire/urban interface.

The locally elected officials are the Mayors, the Councils, the County Commissioners, and your fire district directors. In Summit County alone, we probably have about 20 or 30 different boards that we have to deal with, most of which are elected. Primarily what happens is they look to the three County Commissioners for overall guidance and coordination. County Commissioners are in charge of the planning commissions and building codes and other local controls relating to development.

The challenge, and this is principally for the locally elected officials, is to keep structural fires away from the forests and vice versa. How is Summit County meeting this? We've had some success in this area. We certainly are reacting positively to the wildland/urban interface in our county, because it reflects positive public acceptance to our addressing the issue. That is extremely important, and that is the first thing. If you don't have that then you don't have anything.

The State Forest Service has designated wildfire hazard areas, and the counties adopted the regulations, the maps and so forth, that they have issued. I believe that this started in about 1974. Our developers are required to identify wildfire hazard areas. Any time they develop anything, they are required to give us a map so we don't have to go around guessing about it. We check them through our planning department. In the last 15 years, Summit County has enacted subdivision zoning regulations and construction design regulations that tend to mitigate the problem. As in the case of New Mexico, the State of Colorado allows local governments great discretion in regulating development. And we've exercised that discretion. There are certain areas where we simply prohibit or greatly restrict development. For instance, dead end roads that don't have cul-de-sacs; areas having over 30 percent slopes, and "chimney fire" areas.

One of the most important areas that we've gotten into is to foster intergovernmental cooperation. I've heard about that here all day, but it is really the truth. We have adopted general policies regarding land use development standards, codes, amd regulations that allow local governmental entities, (that is other local governmental entities such as your fire districts) and developers the flexibility to negotiate subdivision agreements and put in subdivision improvement contracts when both such governmental entities and developers sign off with the county. We've done that pretty successfully, though not evenly throughout the entire county.

We have adopted a second way to foster intergovernmental cooperation and developer acceptance. Believe it or not, we have managed to adopt fairly rigid subdivision design criteria that must be met. For example, two-way access, firefighting water supplies, road grade maximums so trucks have access, and minimum standards on road curves and widths and driveways. We even limited the length of a cul-de-sac. A developer can probably exceed the 600-foot maximum, but there has to be some real mitigating circumstances to do so, and it requires fire district compliance or "sign off" and review. (Sometimes, this latter is tough for County Commissioners to accept, let's not fool ourselves.)

We've also adopted regulations for subdivision design criteria that are general enough so that fire districts and the State Forest Service can fill in the blanks, generally in direct negotiation with the developer. Sometimes, a county planning department by itself simply does not have the appropriate criteria to follow, and we have to rely on other agencies to help us. An example is the area of tree thinning for firebreaks. We actually require the developer to work with the Forest Service, the State Forest Service, and the fire districts in tree thinning. We've adopted building codes on sprinkler systems, roof covering, and fire resistant building materials. These are requirements. The overall idea is to keep forest fires away from structures and prevent structures that are on fire from starting forest fires.

Another factor that's very, very important is that we have a follow-up process. We're not expert at it, but we're getting a lot better at it. And the way we're doing it is we enter into subdivision agreements with developers to guarantee implementation of the mitigation methods in the agreement, which is secured by the developer via a letter of credit. But, again, we couldn't do it if we did not have general political acceptance of this approach in Summit County.

There is also another thing that we try do. We try to emphasize cooperation rather than competition among private citizens, developers, and other agencies of government. We're not interested in who's going to win. Because I think if anybody wins it's going to be us all if we work together. That sounds like a trite phrase, but it's really the truth. We simply are not interested in arguing with anybody. We want to get the job done. We've got to much to do in Summit County, we've got too much growth, and too many other issues to do it any other way. It has been my personal experience that the very citizen we are charged with serving is usually the loser in a competitive situation involving several governmental agencies, when he as a developer or individual citizen is caught in a whip saw, so to speak, between competiting agendas.

There are constraints. One is public attitudes. We've heard about that today. In Summit County, most people don't want to live in the tract developments; they want to live in the pristine wilderness. The State Forest Service recently thought up a novel way to get around some of the problems this creates. They took flags and actually went out with the developer and flagged in red the trees that were going to be kept, and then flagged in blue the trees that would be cut. That proved to be a good device for that developer and the prospective homeowners to buy into.

We've got old stands of mature and diseased timber both on our public land and our private land. There's plenty of it - there's plenty in my neighborhood. Some people want to hold on every stick of dead and diseased lodgepole pine on their half acre, and they want their neighbors (and the Forest Service) to do the same. That attitude represents a political constraint. Probably the worst thing we've got, and this applies to Colorado in general, is that the wildfire regulations set down by the State Forest Service and the hazard maps developed by the State, are merely optional for local governments. The gentleman from the New Mexico Attorney General's office said there were only two counties that adopted them there. I don't know how many Counties have in Colorado, but I would suspect a few more than two have done so. Even within Summit County it's uneven. We've got good compliance in the Breckenridge area, but we have rather spotty compliance when it comes to intergovernmental cooperation and working with the fire districts in other areas of the county, primarily because they just don't have sufficient resources, they haven't developed those resources, or are unwilling to do so.

And finally, another constraint is developer economics. I know a developer who has a development that backs right up against the Eagle's Nest Wilderness Area. He voluntarily cut back and thinned trees for a half mile all along the Wilderness area boundary on his property. I recently talked to him and I ask, "Would you do it again?" And he said, "Hell, no. I did it then because lots were selling good." But he said, "Now, lots aren't selling at all." He said, "It's strictly a matter of economics. I'd fight you to the end if the county required me to thin out trees now." So we would have some resistance there, and you always do whenever you get into economics.

In the future, as far as Colorado is concerned, we need to have wildfire hazard regulations that are mandatory and regional. Fire knows no boundaries. I compare it with the economic development commissions that are springing up all over, I think probably all over Montana and certainly all over Colorado. They're usually on a regional basis. I can't see any difference between that and fire regulations, particularly in the wooded areas such as where Peter Kenney and I reside. It should become part of the landscape, like handicapped access codes have become and like the Clean Water Act. I know, as one county, we've certainly responded to the Clean Water Act of 1972. We're experts at it. We want to be experts in the fire prevention business. At least I do. But I don't know whether we're going to get there individually. I don't think we are.

The second thing is that I think we need more working conferences on the substate level, rather than at the legislative level. The latter is not where the action is. The problem is going to be solved, if at all, on the local level where land use review takes place. We may need legislative action. We may need federal action in several areas, but compliance and solutions really start on the local political level.

The third thing is that we need more political awareness. It's essentially a political problem of good land use systems and safe development. And I think where it begins and where it ends is on the local level, where locally elected representatives can frame policy in cooperation with building departments, planning commissions, fire departments, U.S. and State Forest Services, homeowners, and private developers.

REMARKS BY GENE LaBLANC

I am a fire chief who works for County Commissioners. I have five elected County Commissioners, but I don't think I have the problem that's facing you here in Missoula. I would like to talk to you a little bit about how, as a fire chief, we try to address the issue of the urban interface by talking about how we work with developers to get through the issue of how a developer is going to build in our area. If a developer wants to come in and put in a subdivision, he needs to go through seven major steps before he can actually start building. The first time a developer is interested in development in our area, he needs to set up an appointment with our planning department. At that time, as soon as the developer walks in the door of our planning department, the planner encourages him to sit down with all the agencies involved--the fire chief, the sheriff, the water and sewer folks, etc.--and just have a kind of preapplication meeting to discuss in a very general way, what this proposal is going to be. At this stage of the game, there's no secrets. If a developer is going to put in a subdivision, then the issue of fire protection comes right up front before he has a lot of money and a lot of energy put into the subdivision.

The next step is to set up what we call the tentative review. This is a review of the design, the conceptual idea, the proposed subdivision, what it is going to look like. At that time, we at the fire department get a chance to take a look at the subdivision. We look at the present impact level that we have and address such issues as future fire stations, fire station locations, and in some cases we've even insisted on a specialized piece of apparatus if we feel we don't have one close enough to take care of the situation. We certainly get into the issue of egress and ingress, and we require at least two access routes for the general public, and in some cases we require additional access for emergency vehicles. We also discuss in very great detail the issue of water, and water hydrant systems because in our area we don't consider cisterns as an adequate water system. We get into the issue of the wildland. We require fire or fuel breaks and we require thinnings and clearings around the areas. Fortunately, we have a very active division of forestry, the conservation program, and a lot of inmates which can be utilized by the developers to reduce the fire hazard. We also get into the issue of proper clearing around residences, and we get into the sticky issue of fire resistant roofing materials. Probably the most important thing we do at this stage of the game is to advise the developer that if he's going to get into the development business, he must set up some method for maintaining the open space after he develops the project and before he splits for California.

At this stage of the game, the developer has now received our recommendations in writing. He then sits down with the regional planning commission and all the staff members and goes through a formal application in which conditions are listed alphabetically through the process. When it comes to the fire issues, you're looking at maybe six to seven issues that he must address.

About six weeks later, the developer is now in a position to appear before the regional planning commission for a formal hearing to address the subdivision. This is the first public hearing. It's our philosophy that we try to avoid any major disagreements at this stage of the process. If we can't come to an agreement with the developer at this point, then usually his subdivision has got a lot of problems. We try to avoid the issue of fire protection versus the whole conceptual idea that 'I want to build a subdivision here.' Once the public hearing is held and the regional planning commission makes a recommendation, either approval or denial, then the final decision is made in front of the County Commissioners.

Then, we've added what we consider probably the most important step. If the County Commissioners approve the subdivision, the developer, before he can develop it, must come back with a handbook in which he addresses in writing every single condition and explains his solution for each. Then the agencies, the developer, and the County Commissioners sign off on it. At this stage, the developer can start his subdivision.

I would now like to walk you through a development that just occurred in our area to give you an idea of where we're going. For perspective, however, let's first consider a subdivision that was developed west of Reno in the late '60's. Obviously we didn't do a very good job of addressing the issue of urban/wildland fire protection back then. The vegetation is sagebrush and native junipers on steep slopes. Houses have shake shingles and big bay windows. Access is poor and there are no fire or fuel breaks. The potential for a wildland fire is high and control would be very difficult, if not impossible.

Now let's talk about Collins Ranch, a subdivision that came in after we'd adopted our master plan. Fortunately we're in a situation where this is the last major subdivision that's going to occur between the city of Reno and the Toiyabe National Forest. It's a rather large subdivision. We're looking at an area exceeding 3,000 acres and we're looking at a subdivision that's going to have over 4,000 residents plus the typical commercial area. To deal with the planning for this development, we took advantage of experts from the Toiyabe National

Forest, the University of Nevada, and our State Forestry Department. We had, therefore, the advantage of a group effort to address this problem.

One of the problems we had was the issue of access. We required two accesses for the general public in and out of this subdivision plus some additional emergency access for our own fire apparatus. We took advantage of a lot of green belts and the issue of water rights that this development had. Green belts, or open space within the subdivision, provide positions to either hold a fire or start backfiring operations. We required the developer to clear the native vegetation in some areas down to bare mineral soil and to come in with an irrigated landscaping system to address it. Yet we left the ponderosa pines and some of the junipers in place in a landscaped environment. We required roads to be paved, and if they're 32 feet or less, you cannot use them for parking.

This particular developer was interested in utilizing some hiking trails, some jogging trails, and some horse trails. Sitting down, we agreed that we also needed access to get behind some of the lots. We eventually agreed that we could utilize the recreational trails for our small brush trucks, not our Type 1 engines, but some of our Type 3 and Type 4 engines to give us access to the back of this subdivision and into the open spaces behind. These hiking and biking trails go all through the subdivision and allow us access to almost everybody's back yard. Some of the trails are unimproved, but we still can get access with our fire apparatus.

Although the State of Nevada has a law that actually designated high hazardous areas, this development was already started when some of the boundaries were redefined. So we had some political problems trying to get this development totally involved here. We require, if they want to retain native junipers--which is a big issue out here--the installation of an irrigation system.

We took advantage of some of the native water present, and they helped develop some of the waterways, and then got into planting grasses. So this gives us a pretty good, adequate fire fuel break going through the subdivision and around some of the edges. The juniper was left in place and, in fact, the developer is now planting ponderosa pines to bring back some of the native vegetation. Hand crews came in from the State Forestry and pruned the trees, removed all the dead fuels and some of the dead branches.

We required a Class A or Class B roof in this subdivision. We did run into a situation where we had been fighting on individual lots or with individual homeowners over the issue of shake roofs. Some of the agreements we made allowed that if they would remove some of the native vegetation, including some of the junipers, get back into the issue of landscaping from the irrigated point of view, we'd take a look at it from a city point of view. We did finally end up accepting treated shakes, but we're not convinced that 10 years down the road, we're not going to start having problems with some of these treated shakes. I can't believe the amount of energy we put in with people building houses and architects. We would get into horrendous arguments over the issue of treated shakes versus a tile roof. Where we allowed treated shakes we also required extra vegetation removal.

A complete hydrant system was required throughout the subdivision. As I mentioned earlier, we don't consider cisterns to be adequate.

One of things that we're trying to impress upon the developers is that as a fire chief responsible for a fire district, I cannot guarantee adequate fire protection at all times. In this particular area, we feel that the developer has created some of the problems because he did in fact purchase a piece of property and did start to develop it. We are telling the people who live out there that there is some risk and they need to address this risk. As you saw in a news clipping earlier this morning, they had a fire in Carson City which just lies south of our area, where the landowner said he saved his house because the State Forester told him a few weeks before that he needed to clear his property and he cleared it. This particular house did not have a fire truck on it when the fire ran through. So I think the citizens in the area need to accept some risk and not be in a position to feel that every time there is a fire, they're going to have a guaranteed fire truck sitting in their yard, because this may not be the case.

REMARKS BY LOU JEKEL

Commissioner Dussault told us how to deal with legislators. I'd like to take a few minutes to talk about how to deal with commissioners. What's intersting is that we're lucky, Chief LaBlanc has apparently some good strong zoning controls in his county. Frank Smith and the assistant Attorney General from New Mexico have some potential, but apparently New Mexico has not really caught on like it should. Colorado's Summit County seems to be great, but some neighboring counties aren't so good.

My main job is representing developers which sounds like it's the opposite of what we want here. But what's interesting is that all of the developers that hire me in Scottsdale know my involvement with the fire department. We never have any problem with fire codes or with their fire safe situation, because I won't deal with them unless they're willing to basically follow the codes without question. Scottsdale has been a leader, and it hasn't been easy. As I'm sure some of you know, we have a residential sprinkler code as does Palm Springs and some other cities through the United States, which presently requires all new homes that are built, no matter whether they are single family or multi-family, to have sprinklers. Everything in our city is has sprinklers. This helps greatly in terms of reducing the cost of fire protection to the public. There are some good trade-offs too. We allowed different hydrant spacing, smaller mains, use of gray water and several other advantages. Some of the resorts use gray water out of the ponds that they use for the golf courses, particularly if they have a shortage of water. So all of these systems are taken into account to meet their fire needs.

The way we got the sprinkler ordinance through was going to several leaders in the community who were in the home building business. The primary one had been a past president of the Chamber of Commerce. Going to a person who is that active in his community, telling him what it means to the community to have this type of a life-saving system built into the homes, he was able to understand and support us. And after several of the big home builders fell into line and supported us, we were able to get this through. There was a lot of screaming and gnashing of teeth, but now you see home builders advertising all over the place that their homes are fully equiped with sprinklers. So, not it's part of the sales pitch.

Zoning represents one of the best ways to make a community fire safe. You can talk about buying more fire engines and hiring more firemen. You can talk about more cooperation, and we definitely need to talk about more cooperation. but, you cannot plan and be prepared for the type of fires that recently occurred in California or in Nevada, every minute. You cannot afford that. So how do you do it? You do it by zoning.

You've heard the word zoning all day, so let me tell you, for some of you who may not know exactly how it works or what it is. Zoning is the legal use you can put your land to. Zoning and zoning districts, zoning regulations and districts, keep slaughter houses from being beside homes. They keep, hopefully, airports from being beside homes and put them beside industrial areas. They keep homes from interfering with commercial areas. Now, Houston is a big city that doesn't have zoning and you can tell it when you go there. Practically every other metropolitan community has some form of zoning, and most counties have some form of zoning. But the effect is that what we need to do is go to our County Commissioners and convince them, when they have the options, to put in the zoning and subdivision regulations. In some states, they're available, some states they're not. Where they're not available, where they do not have enabling legislation, then we need to go to our state legislators and get them to put in enabling legislation. Effectively, what you are doing, and what we can do in the fire service, very much like Chief LaBlanc is doing, is you go and you keep your own people who are involved, your own fellow county and city employees, to teach them, first, what you need in the way of fire safe areas. Then you educate your planning commissions, your planning zoning commissions, your city councils, your planning commissioners, and get them to adopt only those subdivisions and only those zoning cases that allow and provide for safe access, and you've heard all about ingress and egress and hydrants and sprinklers.

You have an opportunity in almost every jurisdiction that I know of, of two public hearings before a subdivision plat is adopted and before a rezoning is adopted. For example, if a person has a big piece of farmland or a big piece of rural land and wants to put in a bunch of homes close together, maybe multifamily, that has to go before two public hearings. The fire service can enlist the aid of, not only your own people that you work with, but environmental groups and other groups that are interested within the community. They can go to those hearings and they can protest if these plans do not provide for everything you need in terms of the fire protection. Now, it's going to be a long battle before bringing some counties to the level of the Truckee Fire District outside of Reno. It is going to be a long time before you get to areas like Palm Springs and Scottsdale, which have, in some people's minds, outrageously strong codes. But in getting there, what you can do is improve the status of protecting the wildlands as you go along.

We've talked about constraints. What are some of the constraints?

1. Weak enabling legislation. It's very possible that you need to have the State Legislature give the counties and cities more power to put in these kinds of regulations.

2. Lack of 'home rule' for counties. We talked about that at lunch with the county people.

3. Uninformed legislatures and legislators who don't care, as we have heard from Commissioner Dussault, about anything that is not squeaking. If it isn't broken, if it isn't squeaking, if they don't hear about it, they don't want to be involved.

4. Boards of supervisors can be terribly unresponsive if you don't bring it to their attention. The people I think who are here, and more in the wild areas, are much more attentive to this. In Maricopa County, we at Rural Metro, went to a Planning Commissioner and said, "Look, we need hydrants in the subdivisions." This was about 10 or 15 years ago, and were able to get the county to put hydrants in the subdivision regulations. That alone, basically changed our lives in the county. Because trying to fight a fire in a county as big as Maricopa County, which is the third or fourth or fifth biggest in the United States, without a good hydranting system and without good subdivision regulations, is a very difficult task.

5. The public needs to be informed. Developers need to be educated. An uncooperative or an uneducated fire department needs to be brought into the fold. We have the opportunity to build fire protection systems into our homes and into our subdivisions. And, as you heard all day, it's much better to prevent those fires or put the fires out when they're small, than it is to try to correct what a lot of us consider our prevention failures, when you're in a conflagration situation. There's an opportunity to inform the public and the developers of the needs that we in the fire service need to protect homes and to protect the wildland at the same time. And there's an opportunity to plan ahead. So, from a purely pragmatic view point, the bottom line is when you get into those public hearings and point

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out that the public will not be protected and lives can be lost and homes destroyed because simple practices, which are considered routine by many of you, are not provided, the public officials have a hard time not going along.

Through the hearing process, through public awareness, and through working with developers, this can be done. We are not going to handle the interface problem by buying more fire engines and hiring more firemen. We are going to have to have the public and the politicians join with the fire service and with the land developers and the ultimate user, the homeowner, so that we can make it a joint project that we can all afford. Otherwise, we'll never do it and will be talking about it just like we are 10 years from now.

REMARKS BY JOHN JACKSON

You've been hearing a lot of comments about the value of local interagency cooperation, and I would like to share with you some key concepts that have fallen out, or developed, if you will, out of our interface experience in central Oregon. These are concepts that we feel have been an intergral part of what has been the beginnings of a successful risk and hazard management program in the interface area.

I want to talk just a little bit about some of the mitigating sides of things. You've been hearing a lot of discussion using that term today. I'm going to speak based on a frame of reference of experience from the central Oregon Fire Prevention Coop, and also more recently from the Deschutes County task force. A good example of this speaking with one voice occurred last winter. Several homeowner groups in an area south of Bend, which is in central Oregon, literally kicked our door down and were speaking with a single voice rather pointedly. When they got done with us they then went in and started talking to the County Commissioners with about the same type of an attitude. By the time we got it all put together, we found that we had something happening that was being motivated by an epidemic level of mountain pine beetle-killed lodgepole pine. We had been trying for 10 years to motivate people to want to do something to help themselves. The thrust of their speaking in a single voice was "get out of our road, because if you don't help us solve this problem, we're going to do it ourselves, and we really don't care about the consequences." And so, all of a sudden, the County Commissioners, the State Forestry Department, the U.S. Forest Service, the Bureau of Land Management, the Red Cross, and everybody else involved decided we had better get our act together because we are going to get trampled if we didn't.

One of the points that I want to make is that the scope of this interface problem is expanding. It is here to stay, and it is not going to go away. We have heard that, or heard variations of that all day, but that's the bottom line. It's not going to go away. Recall, for example, when we talked about land use planning and the role that it can provide or play in this situation. That's great for new developments. But what about everything that's already out there in the brush? What about the houses that are already burning up with wildland fire situations? What about those that are going to be built before we can get adequate land use planning procedures in place, for those of us who don't have those at the present time?

Consider a couple of points. On one hand we are not dealing with any new ignition sources. We are dealing with this interface problem with people, with their recreation, both at home and out-of-doors, their appliances, everything from automobiles to woodstoves, and all their other activities. We are dealing with people and their fire-starting propensities. It's not different from any urban or city situation. On the other hand, we have heavy wildland fuels or vegetation, often highly flammable for at least a part of the growing season, perhaps for most of it in many places. It's this combination that is starting to give us the problem.

Our ignition prevention programs, our loss control programs, structural fire safety fire approaches, and so on, developed over the years are still valid. One of the things we talk about, especially in the structural side of the fire services, is code. Is something going to meet code? Those codes are designed to protect structures, to keep them from catching fire. If they do catch fire, to mitigate some losses, and so on. But what about the brush? We don't have any codes for wildland fuels. We need some. Because if you're going to stick a house out there in wildland fuels, that's no different than having a lot in the city or a house in the city with dry grass two feet tall and brush and junk and everything else scattered all around. And yet, if it was in a city, what would we do? We would go out there and do something about getting rid of that hazard. We are not doing anything about that in the wildland areas in many cases. If you haven't guessed it by now, one of my real interests is fuels modification or landscaping in these subdivisions. The point I want to make here is that we need to expand our concept of prevention to include large or catastrophic fire prevention. If we are committed to protecting people and homes in this type of an interface setting, we are going to have to devise some methods to insulate them from wildland fuel hazards. Chief LaBlanc talked about some of the requirements that they are utilizing. It doesn't really make any difference whether we are talking hazard reduction or whether we use the term fuel modification or landscaping. We have got to get some of that wildland fuel into code, if you want to use that terminology.

One of the definitions of the interface has been the loss of a clear distinction between urban, rural, and wildland fire protection. If you are not aware of it, you need to be aware of it. Wildland firefighting techniques are having just as much problem with this interface fire situation as are structural firefighting techniques. It was mentioned earlier today that we do not have some of the liberties to back off a quarter mile and put in a five-blade cat line and touch 'er off when you've got a subdivision in the way. That just isn't one of the choices any more. Fighting wildland fires is getting to be no big deal. It is dealing with that interface problem. How do you protect those houses and that value at risk stuck out there in the woods?

Among the solutions that are being considered is cross-training. Another solution that we have been doing quite a bit of is incidence response drills where all the agencies go out, pick a target area, and go through the motions. We exercise our incident management skills and at the same time do what we can to pump up the public and increase their awareness of the fire prevention situation.

There are more and more instances of fire control cat lines and various other wildland fire techniques being built right under the gutters of interface homes. And the growing magnitude of this situation is well documented by the 'Structures Threatened' list that many of us get from the daily situation report. I started keeping track of statistics but gave up after a couple of months because it became somewhat self-evident that I was not going to have any trouble coming up with enough examples to substantiate my point.

One of the especially valuable things that local government can do is to be prepared to let local homeowner groups do things to help themselves. We need to be sure that government agencies and government entities are not part of the problem instead of helping to come up with an answer to the problem.

As I mentioned, in this mountain pine beetle situation we are dealing with, we have an all-agency group, concentrating on one or two local homeowner associations at a time, cutting red tape. We go in, we meet with them, and we deal with the problems and questions they come up with. Having the chairman of the County Commission and representatives of all the fire services plus the Red Cross in the same room at the same time, assures that the homeowners get answers to all their questions. We have adopted the attitude that that is what it's going to take for them to be convinced that we, as agencies, really care and we really have their best interests at heart. So, consequently, they develop a perception of instant or immediate action in dealing with their questions and their problems. I think that there is a need to demonstrate this type of multi-agency coordination in presuppression and preparedness planning as well as suppression. We usually fight the fire pretty well together. We need to be demonstrating that same concept in a presuppression or preparedness planning mode.

The final point that I would make is that a multi-agency, multi-resource approach to dealing with this interface problem, is really critical to avoiding tunnel vision. You get a multi-disciplinary tenor to your solutions and it eally helps to ensure that we don't get off into a blind alley or a dead-end in some our efforts. And we maintain good credibility with the folks we're working with.

REMARKS BY PETER KENNEY

I owe it to my County to clarify some of my earlier comments, just slightly. In the first place, we now know where to send Commissioner Levengood's rednecks. The reason that I want to say a couple more words about my County is that there is a part of this problem that we haven't really spoken about. And it's going to be the case in many other counties besides my own. Also in Clear Creek County, we have adopted the State Forest Service wildfire/hazard area concept. We apply it in every zoning case. We apply it in every subdivision. We even apply it in every subdivision exemption, which is a little trick of the Colorado statute that creates an abbreviated process for dividing land. We do apply those whether it's in access, certainly mitigation, thinning, and we cooperate, in fact, just like Summit County. We require the developer to go to the State Forest Service in order to develop a mitigation plan. We limit development in fire chimney's and on steep slopes. But the problem that we have is that all of these wonderful new regulations and opportunities and the new awareness that leads us to begin to apply them, the new support that we have from the excellent resource in the Colorado Forest Service, is all very recent. I have been involved in Clear Creek County's land use process since 1976 when I was a member of the County's Planning Commission and up to this point as a County Commissioner. And it's only been for about half that period of time that we have really had any significant effort to try to address this problem. Prior to 1973, we didn't even have any subdivision review. It just took place. Prior to 1964, there was no zoning. We have many communities in my county that were built prior to 1964 where the densities are eighth-acre lots out in the forest with no water, no sewer, no roads, but individuals own those lots, and they want to develop them. We have subdivisions that were put on the map, the plats were filed, and they are legal subdivisions that predate any opportunity for local government to comment, much less to regulate. And I think that we have a bigger problem in many areas, not with the future--we're dealing with the present and with the future in a much better way than we ever have before--but we need a way to go back and to retrofit some communities that we have out there that were built without any awareness that there was a problem, or certainly without any care.

And that reminds me of some comments that have been made. Enabling legislation is weak, was one of the comments that Lou Jekel made. And I'll give you an example of that. Two years ago the Colorado Legislature for some unknown reason--I haven't been able to figure it out--removed from the law the opportunity for counties to adopt fire code if their population was below 15,000. That takes half of the counties of Colorado out of the business of fire code enforcement. We need better enabling legislation in that area. We need better enabling legislation in retrofitting, as I said, some of these communities for fire protection.

The reason that I bring this up, and I feel that it's important, is we've also had some discussion about public participation. I've been an elected official in Colorado, first as a mayor, now as a County Commissioner, for 13 years. I have been to a couple million public hearings. It's been my experience that 99 percent of the time when you go to a public hearing, and you receive public input, the people that you will see there and that you will hear from are those people who are opposed to something. The people who support a thought, an idea, a movement, a new awareness, and some better fire protection at the wildland/urban interface, don't come to those public hearings very often. And as one person with a very sincere special interest in favor of fire protection that goes back many years, I need the help of the other special interest groups and the public at large as they become more aware. I need them sitting in front of my table, telling me to go ahead and have strict regulations, have good enforcement and protect the resource, whether it's the human resource, private property resource, or our natural resources.

QUESTION AND ANSWER SESSION

Question by Greg Houley: I'm from Woodland Park, Colorado. I have two questions, the first for Chief LaBlanc and Mr. Jekel. Have you found that your regulations have stopped or depressed development in your jurisdictions?

Answer by Gene LaBlanc: Speaking for our area, no, it has not.

Answer by Lou Jekel: Very simply, what has happened is that the quality of building gets better, and when the quality of building gets better, you can charge more for it. People will pay more for it, and we find that Scottsdale has maintained, for instance, a building pattern--not a boom--but a good, steady building pattern when other areas become more depressed. So I think quality always sells. It doesn't have to be rich and fancy quality, but quality sells. And I think that these codes and all these, everything we're talking about, is on the quality side and that helps sales.

Answer by Rich Levengood: We're finding that in Summit County, also. There's an awareness, there's a tendency towards enlightened self-interest, and I think the better the quality, the more people sell.

Question by Gene Houley: My second question is for you, Mr. Levengood. Do you have written intergovernmental agreements between the county and the fire districts within your county in relation to subdivision adoption and building permits?

Answer by Rich Levengood: Not that I know of. I think this is something we should do, that's one of the things we've got to go back and do. There may be some. We have seven fire districts, and as I said previously, it's rather uneven in the way districts participate in the land use process. It's very good in my area, but it isn't very good in some of the other areas. And they do have a fire authority that they formed through intergovernmental agreement. I would like to see them revitalize or get that issue before them so we have an even response by the fire districts and then, in turn, we will enter into an agreement with the fire authorities, rather than the individual districts. I think it would work a lot better since we have seven districts. We haven't had much luck in consolidating districts. We've been defeated last year a couple of times.

Question by Steve Laursen: I'm with the Extension Forests here in Montana and I was going to ask you whether you were having a problem with homeowners complaining about increased costs for new homes. But I think you answered the question, that they seem to appreciate the higher quality. So I'll switch to another question, and that is, in your areas where your developments already exist and there are major problems with ladder fuels and so on and so forth, and no fire breaks and road problems, etc., etc., what have you done in order to get to those homeowners? There you are talking about an increased cost, you are talking about homeowners who probably figure the probability of them running into a problem is very low. What type of programs have you used in those established developments?

Answer by Peter Kenney: Well, I'll speak for Clear Creek County and very humbly say, we have done nothing. We don't feel that we have had any authority. We've been able to do nothing as a regulatory agency, let me say that. We have tried to educate the communities. Our fire departments, and in Clear Creek County, we have kind of a unique situation. We have two districts, or fire departments. We have four municipal fire departments. We have one private, non-profit volunteer company. And yet, although the jurisdictions were very shaky, very difficult to define whose jurisdiction was what, over the past seven years, those fire departments have come together, organized the Clear Creek County Fire Commission, which was mentioned earlier, and everything from border to border in Clear Creek County has an automatic response plan. What we have done is go into those communities, meet with the homeowners' associations, try to describe for them the problems and solutions that might be available. We have had voluntary cooperation in some of those communities to try to correct some of the problems. Many of those communities are working with the State Forester in order to try to institute some forest management. Primarily, that was in response to disease, unfortunately, both to the pine beetle and the spruce budworm, which are very serious problems in my county. But there has been some response from within those communities but it's been voluntary and there's been very little that the government has felt they had any authority they could do.

Answer by Rich Levengood: We've done two things. We have contributed, out of the County General Fund, money for pine beetle abatement, and I think this year it was something like \$10,000. That's helped. Another thing we have done, which is really politically loaded, is we've created, since I've been Commissioner in the last 2½ years, three local improvement districts. And access and water are paid for by the residents when you create a local improvement district. We've done that through commissioner initiatives rather than citizen initiative. We see the enemy and I guess he's us, and we took the rap on the knuckles and ran with it and created them, because we wanted to correct road problems particularly. One of them was very controversial about a year ago. It was defeated 2 to 1. I voted against it because it was not comprehensive enough to suit me. We just looked at one district and we needed to look at about 10 others. So that's an issue that's still going to be coming to the fore in Summit County.

Answer by Lou Jekel: I think that one area that has not been used is the improvement districts. We have talked about that in Scottsdale in downtown Old Town to put together improvement districts to resprinkle entire blocks of buildings. We haven't quite gotten that done. I think, though, there is great potential in going back to homeowners, at least in Arizona and I think probably in some other states, you can use 10-year tax-free bond money to do improvement districts. And, it may take enabling legislation, but I think something that should be pursued is to go to the homeowners, and say "OK, it costs this much to put in hydrants and it costs this much to put in road. We can get that done and pay for it over 10 years in monthly assessments like taxes." And if you can get their approval, or 51 percent in Arizona, you can go ahead with it. That's something that has not been done much and I think is really an answer to doing the retrofitting that Peter Kenney is talking about.

Question by Steve Laursen: I have a question for Ann Mary. Knowing the process of the master plan and zoning in Missoula County, you would think that we would make progress in trying to incorporate the fire type regulations and go through that process is Missoula County. Is there an avenue there for us?

Answer by Ann Mary Dussault: The experience that we had, when the Commissioners first adopted the Comprehensive Land Use Plan, in implementing it it was found that the zoning, the attempts to zone in all the rural areas failed. Plain and simple. I think that the methodology that we're using now is better in that we're going to those communities and they're developing their own plans and that, because they're doing that, we will see more quickly an acceptance of the implementation procedures because now they own the plan. It's not been something imposed on them.

Question by Ken Cassutt: I'm from New Mexico. I wanted to get back to the issue with the whole panel of increased developer costs. In New Mexico, we have our share of yuppies and marpies in Santa Fe and Albuquerque. But in the rest of the state, what we have are 'dumpies.' Those are downscaled, underhoused, multiple child parents. We end up with a lot of downscaled development in New Mexico. A lot of mobile home subdivisions where you put your mobile home there, you sink your own well, you put in your own septic system, and you're on your own. My question for you is, do you get complaints in your communities that those kinds of people are being pushed out by these increased regulations? And if so, how do you deal with those complaints?

Answer by Peter Kenney: Other than having them move to Clear Creek County? Who wants to take a crack at that? You've raised a good point.

Answer by Ann Mary Dussault: You've raised a good point. And I believe that the Montana Supreme Court has held that we cannot exclude mobile homes, for example, from any residential area, or at least those that were created before a certain date.

Answer by Peter Kenney: We have the same circumstance in Colorado only it's by statute, and not by case law, that adequate mobile homes must be allowed, cannot be prohibited by any zoning in the state. Nonetheless, the problem that you raise is very real that as a result, some of these communities do not adequately address the need for low cost housing. And it is a problem that we have to deal with. On the other hand, I see as a County Commissioner and looking at the statutes that govern my activities, that the primary function, the general description of the police powers of the board of commissioners in Colorado, is to protect and preserve the public safety, health and welfare. It's a problem. It's one that there isn't a good answer to, but as far as my own interpretation of my responsibility, I don't have a mandate to provide unsafe housing for any population.

Answer by Rich Levengood: We have our building officials and our life-safety people in the county work very, very closely with mobile home people, mobile home areas that may be out of compliance to bring them into compliance. We've adopted a stance, as a policy matter, in Summit County, that we were not going to deliberately drive out anybody by virtue of our standards in that county. So, we really go out of our way to work with folks, even old mining cabins. If we can make them safe--they've got to meet life-safety code, and it's worked pretty well. There's been general acceptance.

Question by Bill Barrigan: I'm from Washington. I think the dumpies are moving to Washington and central Oregon and northern Idaho in great numbers, and that really is leaving us with the meat of a problem that we've got in all of these states of the people that are going out in our areas, and we don't even have rural fire protection for those people. We've had problems in our state of Washington. I visited the great state of Oregon and saw the same problems down there where you're putting $100,000 vehicles, fire apparatus, up to the end of roads, and being met by that gentleman with the 30-30 permit that has built a $5,000 dumpie. Then, as a County Commissioner, I guess my question is, how can you justify putting your $100,000 fire apparatus and people in a position of protecting structures of that value that aren't involved in any development process? They're not in a development with a developer. They've got a 20 acre patch and a $5,000 house, and that is all they own. And how can we ethically say we aren't going to protect them? They aren't paying for protection. But how can we ethically pull out and say, "No, if you want to come in and meet our standards, then we'll come protect you." That's what we're running into in the fire services is how do the state agencies and the rurals justify the expense? And it's coming back, saying County Commissioners, what are you going to do about at?

Answer by Peter Kenney: Well, I guess the essential problem that we're talking about today is that if we withdraw protection from that, or that one persons problem is not his problem alone. It's the nature of the wildland/urban interface that a wildland fire, from whatever cause in that area, is going to spread ultimately, and threaten housing, and residential areas. By the same token, if that person's home or hovel catches fire in the wildland, ultimately that fire spreads and threatens other natural human resources. So, I don't think there is any way that we cannot provide for that person's fire protection. On the other hand, there is no way ethically that we can ignore the threat that an unsafe occupation in the wildland places on everyone else.

SESSION 3

Carol Rice, Moderator
Wildland Resource Management, Inc.
Walnut Creek, California

INTRODUCTORY REMARKS - WORKING TOGETHER OR CAUTION: BORDER CROSSING

Carol L. Rice

Working together, or crossing boundaries, is an especially important aspect of fire management in the urban/wildland interface because by definition there are numerous borders, necessitating frequent involvement with colleagues outside one's own organization. The key to success is to make this border crossing second nature before it needs to be done in an emergency.

Land ownership patterns are often fragmented and fire protection boundaries convoluted. All levels of government - federal, state, and local - are likely to occur in the urban/wildland interface. There are boundaries between different agencies within each level of government and between the various levels. Boundaries - both jurisdictional and policy-wise - may need to be made less distinct to enhance our ability to work together toward fire safety.

Another type of boundary exists between goverment and non-government entities. Increasingly, the vital role both the private sector and volunteer fire departments or services play in fire protection is being recognized. Integrating these services and products into fire protection systems represents a boundary that needs to be crossed in the urban/wildland arena.

Finally, perhaps the most elusive boundary is that frontier between the fire management services and the community they serve since the public doesn't know or care about differences in agency policy or jurisdiction.

Fire protection in the urban/wildland interface is a premiere challenge because of dangerous fuels, limited access, high values, etc. We need all the resources conceivably available, regardless of source. Making those resources - human or equipment - available is best done by working together and crossing borders or organizations.

Transcending boundaries isn't always easy. Many issues arise, including those of defining responsibility, coordination, turf battles, duplication of efforts, and communication. The papers in the following session squarely address these issues.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Author is proprietor, Wildland Resource Management, Walnut Creek, CA.

TURF BATTLES--HOW DO WE MINIMIZE THESE STRUGGLES IN EMERGENCY MANAGEMENT?

Dick Montague

Our problem today is that most of us, as managers in the emergency services field, have been brought up during a period of growth and expanded services. We really did not need to seriously consider cooperative relations with other departments or agencies during this period of growth and adequate budgets and were considered as successful managers. Departments were expected to, and thus only provided the essential services for their specific clients. We knew where each cooperator stood in their specific areas of responsibility and chose not to tread on their turf. The definition of cooperation was much different than the one we use today.

Today we are faced with shrinking budgets, an increased demand for multiple services in an "all risk" environment, and a public that is well versed in the state-of-the-art cooperative efforts being implemented around the country. We were never taught how to deal with cut-back management and the turf conflicts that are now appearing with so much more frequency.

What do I mean when I say "turf battles?" I mean those areas of responsibilities where two and often more departments/agencies provide similar services within a given area, except the jurisdictions and missions may be slightly different. A few examples are:

1. Wildland fire vs. structural fire protection.
2. Search and rescue operations. (Emergency service vs. fire departments.)
3. Arson investigations vs. fire prevention. (Sheriff vs. fire department.)
4. Ambulance services vs. emergency medical services. This may be private contractors vs. fire departments.
5. "All Risk" emergency responses, that is, floods, fire suppression, earthquakes, hurricanes, and civil disorders.

The fire services are often faced with providing similar services along common boundaries. Federal, State, County, and local fire departments may be faced with situations in which their neighbor is better financed and equipped, and has the capability to provide a higher level of service to the constituents. Most of the time salary scales and employee benefits may vary greatly between departments. This is usually the case in big city versus the smaller city or volunteer departments along common boundaries. Also, you may be put in competition for budgets, personnel ceilings, and equipment with other departments within your city, county, or state who are willing to provide these similar services at lesser costs. Usually the charters of these departments are quite similar in mission and the most aggressive leader comes out on top.

Fire service personnel cannot provide the excellence of management expected by those we serve if we don't take the initiative and strive toward providing more cooperative efforts between agencies with common responsibilities.

Does this conflict in turf jurisdiction still take place? It certainly does; I would like to mention a few occasions around the country this past summer where the principal jurisdictional agency refused assistance from their cooperators, then proceeded to lose control of their incident. One example was a situation in which one agency decided to send another agency home and then proceeded to lose a wildland fire that destroyed homes within the jurisdiction of the agency sent home. First of all, I question why the two or more responsible chiefs did not sit down together and develop a common strategy that would address the concerns and objectives of all agencies potentially involved. In this particular case, the agency responsible for sending the other agency home was not equipped, trained, or responsible for structural fire protection. They were well qualified in wildland fire protection and, at the time of decision, the fire was only burning on wildlands within their jurisdiction. The structure loss threat was in another fire protection jurisdiction located within the overall boundaries of the wildland fire agency's jurisdiction. The wildland fire agency underestimated their ability to contain the wildland fire within their area of responsibility. They did recognize the potential threat of multiple structure loss if the fire was not immediately contained; however, because the other agency was not trained or equipped for the wildland fire suppression mission being performed at the time, they were dismissed. Most of the time these issues of turf conflicts are not intentionally made to ignore the other agency. They are often made in the heat of the battle and

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Dick Montague is Manager, Incident Management Concept, 1465 Anoche Glen, Escondido, CA 92026.

by personnel not totally aware of the other agencies' responsibilities and concerns.

What can you do to prevent these situations occurring within your jurisdictions? You should volunteer to host a meeting of all your key cooperators and jointly develop an inventory on who has what personnel, skills, and equipment. Next, you should develop strategies on how to coordinate your efforts to use the closest qualified resources and/or shared resources on those incidents where you might exceed your own capabilities or where there is an overlap in responsibilities. Most important of all, decide to use the resources in the areas where they are best trained and offer the highest skill. A good example is in those urban/wildland interface areas where structural and wildland skills are required. For example, assign the structural fire units to the structural fire protection tasks and the wildland fire units to the missions for which they are best equipped and trained. Before you can effectively use these shared resources, you must:

1. Develop common standards and terminology.
2. Use a common emergency organization that all agencies understand and use every day.
3. Establish methods to reimburse each other for services rendered, and
4. Create an interagency decision-making process to direct the operational procedures to be followed.

There are many good examples, throughout the United States, where cooperative departments have gotten together and created an Oversite Group/Board of Directors' concept consisting of the top managers of all the emergency services departments having common responsibilities. These groups/boards can be a representation of multiple counties or be limited to department heads of one specific area or city. Experience has shown that we often start out limiting our concept to a small area and quickly find out that these same concerns can and should be expanded on a much wider scope. I am aware of some very successful Oversite Groups/Boards that:

1. are State-wide in scope.
2. consist of several Federal and State agencies, a large metropolitan city, and four large complex counties, and
3. involve two States, three federal agencies, and multiple county, city, and local emergency services agencies.

There are no set answers on how large or small the Oversite Groups need to be for effectiveness.

The principal key for success in the aforementioned models was the fact that agency top managers got together as an interagency group to both individually and collectively support the creation of an effective decision making process. These interagency decision-making groups took on the responsibility for overseeing the general interagency cooperative operating procedures. The size, membership, and structure of the decision process group was tailored to meet each specific area's need. Members had the delegated authority to implement these jointly prepared procedures within their own specific agency. The decision-making group provided the interagency direction to subordinate interagency supporting committees consisting of technical experts specializing in their specific functions. Some examples of these supporting committees are:

1. Safety and training
2. Communications
3. Systems and computers
4. Hazardous materials
5. Specialized fire equipment
6. Standards and qualifications

The supporting committee's role was to recommend the operational procedures, standards, and certification for performance criteria in their specific area to the oversite group for adoption by all participating agencies. In most cases, the oversite group established an interagency coordination center. When resource needs exceeded any one agency's capabilities, this center would then become operational and provide a single point ordering source with authority to set priorities and screen duplication of orders. This type of coordination center may be a 24-hour operation or it may be activated with trained specialists upon demand. Representatives to these coordination centers must have delegated authority to make agency decisions on whether resources can or cannot be obligated to a single incident or multiple incidents.

The establishment of preplanned interagency incident management teams was another successful factor in the cooperative efforts found between these agencies. The oversite group established common qualification and skill standards and selected the participants for these interagency teams.

Interagency incident management teams should consist of representatives from all participating agencies. Occasionally, the leadership (incident commander and/or operations section chief) roles may change based upon the type of incident, for example, sheriff in law enforcement, search and rescue incidents, and fire chief in fire and medical assistance missions. The principal support section chiefs of planning, logistics, and finance would remain constant. Incident information and safety staff would also remain the same on the team.

Another approach is to use the unified command concept of multiple incident commanders working together to set the incident objectives and then select one operations section chief to implement a plan to meet these objectives.

It is a well-known and accepted fact that personnel who train together, use common terminology, have joint or co-located dispatch centers, and share the closest available resources, are providing their taxpayers with the most cost efficient and effective form of emergency services.

The reason I surfaced the aforementioned methods of cooperation is the fact that these state-wide and local area cooperative efforts have and will continue to be the focal points for other wildland/urban interface efforts. This is especially important in those areas where a united front by all is a "must." One that comes to mind is in fire-safe guides for living in a wildland/urban interface area. Others will talk more about this subject later in the program.

Throughout the country we have had several examples of "turf battles" that made front page headlines in the newspapers or television programs. In almost all cases, the participating fire departments came out with a "black eye." I am concerned that the images of the fire services are maintained, but I am much more concerned that the real issue of what is required for the private citizen to live safely in the wildland/urban interface area was lost in the smoke by the media covering only the issue of "feuding fire chiefs." Public hearings that surfaced after these fires focused on improved cooperative relations, who improperly used the resources available to them, and really did not address the real issue on how to "SURVIVE A FIRE IN THE WILDLAND/URBAN INTERFACE."

How well are you and your cooperators doing in this cooperative work?

PRIVATE ENTERPRISE AND FIRE PROTECTION SERVICES:

A LOOK TO THE FUTURE

Louis G. Jekel

ABSTRACT: Contracting fire protection has been with us for a long time. Now more and more private contractors are entering the marketplace. Economics dictate that new ways be developed to address the ever-increasing costs of fire protection. This is particularly true of smaller resource units with lower overall fire danger. Contracting all elements of the wildland fire protection program can be another tool available to the land manager.

INTRODUCTION

Contracting wildland fire protection has been commonplace for many years. What is new is that now some of the contractors are private corporations. Private fire departments sprang up in many parts of the United States after World War II when war surplus fire equipment was plentiful and relatively cheap. These fire departments were rural in nature and although they began primarily as structural fire departments, over the years as the urban dweller moved to suburban and rural areas, these fire departments found themselves more and more part of the wildland fire protection system.

Historically, many components of the Nation's wildland fire protection system have been supplied by private independent contractors. Catering, aviation, transportation, earth-moving equipment, emergency medical services all have from time to time been supplied by private industry. The move to actually contracting suppression services is a logical extension of the cooperative effort private enterprise has played in the past.

OVERVIEW OF RURAL/METRO CORPORATION

Rural/Metro Corporation was founded in 1948, in the unincorporated suburbs of Phoenix, Arizona. Since that time it has grown in size to an operation involving some 1,800 employees in five states, providing a full range of fire protection, suppression and emergency medical services.

Rural/Metro provides contract fire protection and suppression services to numerous cities, fire districts and unincorporated areas within the States of Arizona and Tennessee. It provides ambulance service in Arizona, New Mexico, Texas, Tennessee and Florida. Rural/Metro has provided wildland fire protection services to the United States Forest Service, the Bureau of Land Management, Bureau of Indian Affairs, National Park Service and the State of Arizona.

All full-time Rural/Metro fire fighters are certified basic emergency medical technicians, with many of them certified paramedics level. Because Rural/Metro has historically been a rural-oriented operation, it has always operated between metropolitan population centers and the wildlands. Of all structural fire agencies in Arizona, Rural/Metro has the greatest wildland urban interface exposure; primarily in the Tucson/Pima County area and the Phoenix/Maricopa County area.

BUDGETS NECESSITATE NEW APPROACHES

An analysis of the inner-workings of a major wildland fire organization will show many segments of that system that either are already contracted out, or very well could be. The question, therefore, is why is it just now that private enterprise is beginning to participate more actively in the wildland fire protection system? The two primary reasons probably are budget and acceptance.

Over the years the budget constraints on wildland fire organizations have grown to the point where managers and administrators must find alternatives to the conventional and sometimes expensive creation of separate fire organizations. Acceptance, on the other hand, has been gained by companies like Rural/Metro who have been in the business long enough and who have patterned their training and incident command procedures after those developed by the governmental wildland fire organizations. What really makes contracting attractive to the government fire manager who has a problem to solve, is the flexibility that a wildland fire organization can provide.

In studying the major fire organizations throughout the United States, be it the fire department of New York City or the United States Forest Service, one sees that where fire occurrence,

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Lou Jekel is Chief of Fire Management, Rural/ Metro Corporation, Scottsdale, Arizona.

risk and exposure is the greatest, it is clearly the easiest to provide a strong and economically justifiable fire organization. Where the real problem is, and where private contracting is more and more seen as the answer, are those areas having shorter periods of less intense fire activity on a sporadic basis. There are many land management units within the United States that have either very little fire problem or have fire seasons of very short duration, with intensities that vary greatly from year to year. These land management units are ripe candidates for contract fire fighting.

The new module that will appear will be a full-service, "portable" fire department. The portable fire department will be a total fire protection, prevention and suppression module, that can be moved from area to area on a predetermined schedule. Flexibility permits, during those rare years that a low fire danger area experiences high fire danger and the season becomes elongated, the operation to stay in place on a week-to-week or month-to-month basis until the fire danger drops and the fire department moves on.

The cost savings in not having to support a 12-month fire program to deal with a two-month fire season will be astronomical. This need not be a threat to land management units having fire organizations who will then be freed up to handle more serious fire problems. A transitory contract system can maintain continuity of people who are in the fire protection business on a full-time annual basis, only in different locations. The fire prevention program and overall fire management goals of a contract would be administered as in the past by the receiving agency, but a highly mobile, well-trained, well-equipped fire suppression organization would move in, set up, do the job and move out at great cost savings to the public.

CONCLUSION

In final analysis, private fire organizations become just another tool for the fire manager in doing the job. Cost effectiveness will be the watch word and will make it very desirable for the public and private sectors to continue to enlarge their already existing partnership.

GAINING COMMUNITY AND PUBLIC SUPPORT TO SOLVE THE WILDLAND RESIDENTIAL FIRE PROBLEM: A PANEL DISCUSSION

Bob Lee, Gary Severson, and Ron Hodgson

REMARKS BY BOB LEE

My remarks are designed to provoke you a bit, perhaps to anger some of you, and I have departed substantially from my prepared remarks in order to discuss the topic of who is ultimately responsible for solving this interface wildfire problem.

What worries me is that I think we are searching for some new technological fixes - new fantasies, if you will. Our response to the interface fire problem may turn out to be as counterproductive as was our attempt to exclude fire from natural ecosystems in the temperate regions. We may be just as irrational and just as fanciful in our thinking as were the people who set out to tame the fire demon. I was quite surprised when I came in yesterday and saw the dragon slayers poster paper - saving the damsels from distress. At the University of Washington, we're teaching our young women to practice assertiveness tactics and to take responsibility for their own lives. It's the age of the new woman where the woman doesn't need the knight to protect her from the dragons, and I would suggest that perhaps it's also the age of new fire management where responsibilities are allocated a bit differently than they have been in the past. The age of chivalry is past. It's too expensive, it doesn't work very well. I would suggest that a lot of our current fire management practices, fire suppression practices, are equally outdated.

We have to ask the question, who is responsible for solving this problem, and who pays? Our failure to define these responsibilities is at the very root of the problems we have been discussing here for the last day and a half. Better suppression, no matter how well it is organized, through all kinds of communications advances, is insufficient and is potentially counterproductive. Let me repeat that. Better suppression is insufficient and potentially counterproductive. Why is that? Because it raises unrealistic expectations on the part of the public that we, wildland fire agencies holding hands with local protection districts, can save your home. We all know we can't do that. We can't stop all these fires, and in the process, we are losing enormous amounts of wildland resources in watershed, timber, wildlife values, wilderness values, and other resources in wildland settings. There are some analogies to this, in the kind of irrational approach that we take to trying to solve some of our problems in modern society. Flood control is one. We built dams and said, we now can control the flow of rivers. So what did the people do? People moved down closer to the river in the flood plain. And so it resulted in more people getting flooded out than had ever happened before because people thought that now that there is a dam upstream, there won't be the ravages of floods that we've seen in the past.

In our cities, we've espoused a very idealistic, and well-motivated objective of integrating the races. We've said "we'll put them together in schools by busing them." What have we done? We have produced residential segregation where the inner cities are now dominately ethnic and poor and the suburbs are wealthy, middle-class, and white.

And so we haven't looked at the unanticipated consequences of many of our policies. These policies have been misguided and irrational because they haven't taken into account that people respond to what we do. They are part of the problem, and they are ultimately the solution.

Let me take just a few minutes to talk about some experiences that were quite poignant for me this summer. As a forestry student, I worked on California's Mendocino National Forest, in the county where I grew up. All of the silviculture I did then has burned up during the last month and a half. In fact, there is very little actual forest left on the Mendocino National Forest. You look at the rest of that county, Lake County, California, for example, is similarly burned over. In the 35 years that I've been recording these kinds of experiences in my head, gathering these impressions, I've seen the steady degradation of the forests of that county, the conversion of

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Bob Lee is a Professor, University of Washington, Seattle, WA.

Gary Severson is President, Dynamic Horizons, Evergreen, CO.

Ron Hodgson is a Professor, California State University, Chico, CA.

forest to brushland and grass. There's something wrong with our fire policies.

What are the failures here? One of them is that we have failed to understand the role of fires in temperate forests and, by excluding fire, have produced conditions where fires are even more destructive, and those 200 and 300 year old trees that I knew as a child are now dead. How did they persist there for 200 or 300 years in the presence of fire? They persisted because fires were frequent and had burned periodically through the forest, taking out the undergrowth but not killing, or very seldom killing the overstory trees. That's one lesson we've learned and hopefully we're trying to correct.

But I think we're now facing the same problem in another way and with just as irrational a response, in the interface fire problem. We're allocating our fire suppression forces to protecting homes at state or federal expense, very largely, we are then leaving the rest of the forest to burn. And a good part of what has happened in the county I came from, in losses to the forest land base, is a direct result of a diversion of fire suppression forces from protecting the land to protecting homes; homes that were built there by people who simply didn't realize what they were getting into.

We have compounded the losses through fire exclusion, and we have further accelerated these losses by not allocating responsibility to where it belongs with rural residents. What is the solution to this problem? It's very simple. If you look at our legal system and what we have done historically in this country, people who build a home in a rural area are responsible for the costs of fire protection. Yet we find federal and state wildland fire protection agencies increasingly picking up the costs of playing the knightly role of saving the damsel in distress. The action that's required to solve this problem is the mobilization of these people and reallocation of responsibilities. I realize that's a very impractical statement. But I think someone's going to have to start looking at it rather seriously.

Local fire districts are going to have to be formed and the people who live there are going to have to pay the true costs of fire protection. They're going to have to similarly undertake those loss reduction tactics we've been talking about here. Look at the tradition of ranching communities in the West. They didn't have federal and state fire suppression forces. And they learned how to treat hazardous fuels, they learned how to burn around their barns and their fences and their homes, to use plows to create fire breaks to reduce risks, and I think those same survival tactics will have to be learned by the people who live in the rural sector.

There's also some very theoretical reasons why we can't solve these problems, because if we take it on as our responsibility, whether we're researchers, teachers, fire department officials, foresters, we can't know enough about the problems to engage in rational planning. We simply cannot do it from the top down. Knowledge is socially distributed throughout society. We need to mobilize that knowledge to people who live there with those problems, and we cannot coordinate all of those independent initiatives out there, all of those people doing all those different things. They have to do that on their own. The only motive they're going to have is the knowledge that they're ultimately responsible for protecting their structures. They have to build fire districts, tax themselves, and provide the services that are appropriate.

In conclusion, I'd simply like to say that we have to look very carefully at our policies to make sure we don't create unrealistic expectations. We can get ourselves into serious legal trouble by telling people now that we have NIMS and ICS, and all these good things, that we can protect your home. That's not true. We simply cannot make that claim. I think we have to be honest with people and tell them, "you have the major responsibilities for protecting your structure. Our responsibility as wildland protection agencies is to protect the forest resources. We will help where we can in making sure that fires don't burn into urban areas or into rural residences, but we cannot always be successful." And with this reallocation of responsibility, people will begin to undertake, to adopt, some of these practices that we've been talking so much about here at this conference. So I'd encourage you to look at that and to examine legal and political mechanisms by which this kind of redistribution of responsibility can take place. It's consistent with American legal traditions, it's consistent with decentralization, and it's the only way in which we'll ultimately solve the problem.

REMARKS BY GARY SEVERSON

My experience includes working in the area of public participation, and working in the areas of community and acceptance and resolution of community issues over some extremely controversial issues. Finally, I come to you as a homeowner and Bob, you gave me a double whammy this morning. My home sits in a canyon with a major stream running right past the front of it and I've got a mixed stand of Douglas-fir, ponderosa pine and lodgepole that comes down into my back yard. And I do have a shake shingle roof.

The situation that we live in in my particular community is very interesting. I'm going to relate this situation to, not the fire problem, but rather the flood problem in talking about how we might be able to work better with communities and get people to understand exactly what's happening out there.

My particular community, Evergreen, Colorado, is part of Jefferson County, Colorado. About half of the county is plains, about half is mountains. The bulk of the population lives on the plains. We have three County Commissioners, two of which represent areas on the plains, one of which represents those of us living up in the hills. The Federal Emergency Management Administration (FEMA) basically told our county that you, Jefferson County, you're either in the program, or you're out of the program, when it comes to flood insurance. It's either all or nothing. And, boy, it immediately put the County Commissioners right on the spot. The studies that were used to calculate where the flood plains and the maps that were drawn, were less than sufficient. The maps were drawn at such a scale, using a broad tipped felt marker, that you couldn't tell whether your property was in or out of the flood plain. If adopted, the program cost was to be borne by you if you wanted to find out for sure, the data that was used was from an entirely different drainage whatsoever--the Big Thompson drainage, not the Bear Creek drainage. And I'm sure most of you have heard about the Big Thompson flood, an entirely different geologic structure than our particular canyon; it drains the Continental Divide, ours doesn't, and so on and so on. And yet, they used that model, and a "National Model" to make decisions for those of us who are living right there.

The big problem that FEMA made was that they didn't take the time to find out what was important to the people. Yeah, it's easy to say protecting your homes and protecting lives from flood and so on is extremely important, that you folks up there, living in that canyon, you've got a problem. But you see, the people living in that canyon, my neighbors and myself, we didn't think we had a problem. And so, when someone comes in and says "you've got a problem and you need to do something about it," and if the people living there don't even think they've got a problem to begin with, you're not even to first base. And the communication is totally blocked at that particular point. We had the evidence to show that we didn't have a problem. There had been no historical evidence of a flood in that canyon whatsoever. One of my neighbors owns a geologic consulting firm. He had his firm come up and take all kinds of core samples. They found lots of glacially deposited soils but no water deposited soils whatsoever in that particular canyon. And yet FEMA didn't want to look at any of that data. They didn't become familiar with our community. They didn't become familiar with our goals and our objectives. They didn't become familiar with the fiscal realities of our particular community. They weren't aware of the social and cultural uniquenesses of my particular community, or its history or experience or the geographic relationships that we have that are very unique within that county. It was folks putting the County Commissioners on the spot - it's all or nothing. Either the entire county is in the program or the entire county is out of the program. In short, they didn't really do a perception of need, and therein was the problem.

The second thing that happened there was that all choice was taken away. And I'm sure that Ron and Bob both could talk about this phenomenon of choice. Choice is extremely important to the individual. Peter Kenney, a County Commissioner for our neighboring county, talked about the people in Clear Creek County being rugged individualists. Well, we're all rugged individualists, because we all want to preserve choice in our lives as much as we possibly can. It's extremely important to all of us that we have choice. Henry Ford once said that you can have any color car you want as long as it's black. And it used to be that you could have any color fire engine you wanted as long as it was red. And I'm glad to see that maybe now there's some white ones and some chartreuse ones and who knows what other colors are coming out out there. But choice is extremely important, and whenever there's any kind of a program change that needs to take place, choice has to be a very important part of that. FEMA gave no choice - it was all or nothing - one or the other - no choice.

The perception of choice that an individual has directly relates, then, to how much constructive communication there is going to be. And if that individual feels that there is a wide range of choice in helping to shape the program that is eventually going to come out, there will be a great deal of constructive communication taking place. And I think we'll find that the collective wisdom isn't in Washington, DC, but it's clear across the nation. And there's as much wisdom in Evergreen, Colorado, in particular on upper Bear Creek Road (that's where I live), about the area that we live in and, in particular, about the things that affect our lives, as there is with agency administrators in Washington, DC. And we have good ideas at our level, too. Ones that we can live with because we're the ones who eventually end up living with it.

So this whole business of choice is extremely important. And I would hate to see a program, and I don't think it's the intent here, for any wildland/urban interface fire program of whatever kind, that would become a national program directed from national levels and given to or directed to local areas with no choice on their parts whatsoever. I don't think that's what you want, and speaking as a homeowner in this particular case, it's certainly not something that I want. It just won't work. Not in 1987.

Choice has to be meaningful and real. Our volunteer fire department in Evergreen is one of the finest volunteer fire departments around. And they do a lot of training of the volunteer fire department members. Our fire chief has taken it upon himself this summer, as result of last year's conference in Denver, to begin working with homeowners and allowing them choice in determining what's important to them about protecting their property. He's not telling people they've got a problem. He's saying, "Hey, you've got a really wonderful opportunity to live where you live, and here are some suggestions that you might want to follow in helping to protect that investment and that lifestyle that you have chosen for yourself." All of us are involved in choice. It's extremely important. The key to choice is meaningful involvement, and then meaningful involvement of the people is the exercise of that choice. And if you don't have it, you're not going to have a program that works. It's going to be just another bureaucratic program that we're trying to drive down people's throats, and that's the way we looked at the flood insurance program from FEMA.

The third thing that we have to look at, in working with communities, is convenience. You folks, especially here in the fire service, it's your life, it's what you do, it's the most important thing to you, it's your career, it's what you've chosen to do. An extremely hazardous choice, I might add, but you've chosen to do it. Well, that's not the same agenda of everybody else in the world. And so what may be convenient to you, in working through a fire program, or protecting homes and communities from fire, may not be convenient for other people. I've got a shake shingle roof. For me to strip all those shakes off of that house at this present time, and to replace it with some other type of roofing material, ain't convenient. Especially in my pocketbook. And we can sit here, and I can get on all kinds of guilt trips about my shake shingle roof, and I've heard a lot about that, but my fire insurance is paid up. And under the current situation, that's fine. And I'm doing some other things around the house. It's got to be convenient and people have to be able to have that choice of finding out, first of all, what they can do that's convenient to them. And I agree with Bob Lee wholeheartedly, that the responsibility for those of us who have chosen to live in those areas, must rest with those of us who do live there. But what are the things that we can do that are convenient and are within our realm of doing. That's what we need to know and that's what we need to find out.

The fourth thing, then, is a commitment - a commitment on the part of the fire services to work through this problem, this situation, and a commitment on the part of the homeowners and so on, to work with the fire agencies in doing something about it. The result of the FEMA situation in Colorado was that we organized so successfully there, we defeated the flood insurance program for Jefferson County by a vote of two to one from the County Commissioners. So, FEMA pulled out of the county. And now, the creative solutions begin to occur. The County, my homeowners association, my community, other emergency agencies within the county, are creatively working now for alternatives to the FEMA program. And I noticed just the other day that FEMA is now beginning to look at the fact that maybe Jefferson County is really two counties, and to look at the areas of the county below 7,000 feet and those above 7,000 feet as two separate programs. And now we're beginning to get some reasonable solutions discussed, coming primarily from the grassroots level.

If we want to do something with our interface fire program, we need to realize that it has to begin at the grassroots. You see, we can talk about the problems of homeowners all we want. But I know if I went to my homeowners association today and I said "Hey, we've got a problem with fire!", one of the first things they'd say is "well, I'll tell you what, I'm an adult, I made a choice to live here, I know what the risks are. And number two, there's a lot less risk in living up here than there is down in Denver. If you don't believe me, just go down and listen to all the police and fire and ambulance sirens going all night long, and you tell me where the safest place is to live." And until we can come to some kind of an agreement and not be paternalistic about it, but understanding that people have made a choice, and now how can we help them enhance that choice, then we will have a program that really does work at the grassroots.

REMARKS BY RON HODGSON

I'm coming to you as a fly-fisherman. I have some nomex but I always keep it well-washed and neatly pressed, and I always keep my whites greased and brushed, and I always wear my blue hardhat when I'm around a fire camp because I don't want anybody mistaking me for somebody who knows how to use a pulaski.

I'm a communicator. It's time to learn how to promote defensible space to people who live in the interface. I want to add to some of the things that have happened here. And maybe it's time to roll up our sleeves, take off our coats and look at some useful kinds of things we might do. How do we communicate with people out there? How do we deal with this situation?

The people we want to communicate with out there live with each other in neighborhoods. They're not scattered all over the place. We usually want to communicate with clusters of people who live in neighborhoods, and those neighborhoods usually are placed right in the fire hazard. Neighborhoods are made up of people who are linked to each other by interpersonal communication channels. What that means in English is that you talk to your neighbor about all kinds of things, and when something important comes up, you ask him, "do you think that's a good idea?" You may ask it directly or you may ask it indirectly, it depends on how concerned you are about whether you're going to look foolish or not.

People don't make important decisions by reading, watching, or listening to the mass media. People don't decide to tear off a shake roof and put on a metal roof, for example, or a composition roof, by seeing an ad in the newspaper or watching some program on television, even if it includes a lot of flames and smoke and excitement. When people make those kinds of decisions they check with their opinion leaders. There are one or two people in the community who may make their decisions based mostly on what they know from the mass media or people from outside the community; the rest depend to some degree on what opinion leaders feel. There may be people who are aware of fire and understand fire better than the average person in the community, and those people then, may be opinion leaders. Mass media alone isn't going to do it. The Smokey the Bear campaign will keep people aware, but it's not going to get people to change their behavior. What changes peoples behavior is interpersonal communication with their friends and neighbors.

This is starting to look even worse, isn't it? First of all, we've got the problem that we're not doing the right thing because it's their thing, and they ought to be taking the responsibility; now we can't even use mass media to communicate. We've got to solve this problem somehow.

People aren't concerned about fire safety all the time. There are three parts to a fire at least. There's the before, the during, and the after. What people are concerned about before, during, and after a fire is quite different. A recent experience--we had a community that was threatened by a fire on two sides. The fire was moving a little more slowly on one side than on the other side, but it looked like this community was going to be gobbled up. The strike team in there went around the community and said, "this house we can save, that house we're not even going to go near." People asked "why not?" "Well, you haven't got a driveway big enough for an engine, in fact, you can't get a large automobile up it, and you've got no water, and you've got brush growing all around it, and so we can't do anything about it." This was in a public meeting, not one-on-one. Friends and neighbors were around. People said, "well, I guess you're right. I've got a whole drawerful of citations from the Forest Service Fire Prevention Technician that told me I was supposed to fix those things; so, OK, if it comes, that's it." They made a decision there. They had made a different decision before. See, your attitude may be a little different during the fire than it is before the fire. After the fire you've got a recovery situation. There are different stages in the fire experience that are going to make a difference in what kinds of messages people are going to want to pay attention to.

Also, people make rational choices more often than we imagine. Often people who are making those choices do some kind of a benefit/cost analysis whether its monetary or emotional. Sometimes they behave as they do because they don't know what's going on. Often, though, people are making decisions when they really know what is going on and they have looked at their alternatives. You've made choices to be firefighters; maybe you've gotten out of the firefighting part of it and stay around the fire camp like I do, but at least at one time, you made a decision to fight fire. That was a dangerous choice; people in their right minds would not choose that kind of an occupation. So, as long as I'm talking to all you crazies out there, I feel more at home. People who choose to live in a dangerous place may not be any crazier than we are.

People have an agenda, and we have an agenda, and their agenda and our agenda often are quite different. When we think of communication, typically we think of how to choose messages and choose media to get a message out to them to persuade them to do what we think that they ought to do for themselves. Since we're not them, we have a hard time making those kinds of choices. If we rationalize and optimize for ourselves from what we know and the kinds of values we have, we're probably not going to make the choices they would make. We won't choose the media they would and we won't tell them the kinds of things they would ask to know. On the other hand, when they communicate, they look for the kinds of things they think they should know, or want to know, from the people they trust, and from their favorite medium, whether its interpersonal or mass communication, so that they can better do what they want to do. Not so they can better do what we want them to do.

Now, there are two differences here. In one case, you think you're passing a message out to them to affect what they do about fire safety. And in the other case, they're looking at the situation and saying, "I've got all of these choices out there of media that I can pay attention to, I can watch television or listen to the radio, I can read newspapers, I've got hundreds of newspapers I can choose from, I can read magazines, I can talk to my friends and neighbors, I can walk down to the fire department and talk to them, I can check with universities, I can call my uncle in Santa Barbara and ask what he did when the fire came. I've got all kinds of alternatives, and whether I choose to listen to your message or not depends on lots of things, how I think what you have to say matches what I need or want to hear."

Does that mean that we can't communicate with them? No, not at all. We can communicate with them. Now this is where the hypodermic needle and the fly-fishing comes in. The idea that we seem to accept without even thinking about is that the mass media are like hypodermic needles. All we have to do is get the right hypodermic needle and the right solution, (the hypodermic needle is the medium), choose the right needle (a big one), and get the right solution in there, and then when you see an unsuspecting interface homeowner, inject it. Immediate, powerful impact! If we could just choose the right message, choose the right Smokey the Bear or Woodsey the Owl or whatever, we could get a message out there that would strongly impact the people, they'd change their ways, see the light, and become converted. They'd all move back into the cities and leave the wildlands alone!

You've heard some other images of the hypodermic needle. People have told you if you worked with the media, 'don't use the shotgun approach - use the rifle approach.' There's a kind of a hunting image to that. I prefer the fly-fishing model. If you are a fly-fisherman, you've studied fish behavior, and gotten up at inconvenient hours to stand in inconveniently cold water, and fished in places where you lose a lot of flies, and you do that because that's where the fish are, and that's when the fish want to eat. Then you "match the hatch"; you provide something that looks like what the fish are looking for. If you're skillful at it, you'll catch fish. Now, that's how you have to communicate. You have to match the hatch. That means you have to find out what their agenda is, what their motives are, and put your message in that form. You must provide people with the kinds of messages they want, when they want them, and where they will look for them. They will pay attention to your message if it is attached to something they are looking for.

I want to go through a series of slides right now, very quickly, to show you how you would go about working that kind of a strategy, how you would match the hatch.

Slide 1: (Promoting wildfire safety among homeowners: A social network perspective.) I'm going to use that social network perspective, the fact that people are interlinked to each other, remembering now that they've got their own agenda, their own values, and their own motives.

Most decisions are not made all at once. The mass media doesn't hit you and you say, "Doggone, I'm going to go out and change that roof right now." You become aware of it first. The mass media is good for creating awareness. You become aware of the fact that you've got a problem. Then you go through a stage of persuasion. The mass media don't help you at all there. That's when you talk to your friends and neighbors and find out whether you're going to look dumb if you put a tin roof on your house. In some places, you would. You would no longer be invited to the bridge games. At the decision stage, you commit resources. Not only can you make up your mind that you're going to change your roofing material, but then you've got to figure out where you are going to get a loan to do that, when you are going to get the time, where you can find a contractor. All kinds of things have to happen at the decision stage. When you've committed those resources, you can move on to an implementation stage. This is when you actually get the work done or do it yourself. And finally, you've got to confirm that it was a good idea. A roof, if you get it changed, will probably stay on there. But brush clearing around the house will not, the brush will grow back, the grass will grow back. So every spring, you've got to go out and clear around your place. That confirmation stage has to be constant. People have to keep being reminded that, "it was a good idea to do this; it's still a good idea to do it; I should get out there and do it."

Slide 2: (Analysis) The first step is an analysis. At this stage, you have to find out what media are available--the mass media, and the interpersonal networks. Many communities don't have much mass media. When the newspaper comes out once a week, you can't rely on it entirely. You may have to create your own mass media which may be flyers or posters, or public meetings, or talks. Evaluate the interpersonal communication networks. Who talks to whom, who are the opinion leaders, who are the key communicators and the people in a position to get information out to other people and to influence their attitudes and values and beliefs.

Technology assessment: this is a pretty important step. Is clearing around houses consistent with homeowners' values or beliefs, or are you going to ruin something important to them by removing the brush? They may live in that environment, for example, because it offers a sense of prospect and refuge, which is a psychological description of the fact that people like to be where they can see out and still be surrounded and protected. Prospect and refuge may be one important environmental value that people will want to preserve in any firesafe program of landscape modification. There could be others. We need to know how our recommended clearing effects these values before we promote it. Maybe modifications can be made.

The assessment of firesafe "technology" should also take into account the degree to which people might see it as hard to understand or use. An idea that is too complex will not be adopted easily. If people think firesafe is too complex, we ought to try to make is simpler in their eyes.

People should be able to see the beneficial results of firesafe practices. Firesafe clearances are easy to see but they may seem ugly to people who have the kinds of values I speculated about before. The real benefits are hard to see unless a fire threatens. However, effective use of the mass media can overcome part of this problem. At least some people will be able to imagine their own situation if fire information officers are able to demonstrate the effectiveness of clearances to the press covering urban/wildland interface fires. We need better ways to make the benefits of adopting firesafe practices visible to people.

What are the advantages of firesafe clearances compared to the alternatives? This relates to the values one has for the wild landscape relative to the size of the risk and potential losses from wildfire. If we look at that closely, if may not be "economical" to do clearances. Even when only the potential loss of a house is considered, it may not "pay" to do clearances given a relatively improbable fire and the protection of insurance. How can we make firesafe practices have a higher relative advantage?

It should also be possible to try the firesafe idea out a little at a time. That is hard. One can never really try it out without a fire. However, again, careful use of the mass media and local interpersonal contacts, maybe with simulators of some kind, can help people apply the firesafe idea to their own situations. Related to this is the need for the firesafe practices to be adaptable to different situations. Everyone faces a different environment and economic situations. If there is only one kind of firesafe, it will not fit everyone's needs.

Slide 3: (Awareness) Having analyzed the communication systems available to you and the technology, you are ready to begin promoting. The first step is to create awareness. This is where mass media can be very effective. However, it is important to make sure the opinion leaders in the communities know about the new idea and have a positive attitude toward it before people start asking them about it. That usually means that you have to make personal contacts with opinion leaders directly or through organizations they belong to. Direct contact is most effective.

Awareness means that people know about the idea and can see some potential application to their situation. They haven't developed an attitude about the idea yet. Persuasion is the next step in the process of deciding to adopt or reject the idea.

Slide 4: (Persuasion) During the persuasion stage, people form attitudes and opinions about the new idea. This is where people will decide whether firesafe is a good or bad idea as far as they are concerned. They will consider the relative advantages, the compatibility, and the complexity of the idea here and whether it can be adapted to their particular situation. Opinion leaders will be very important at this stage. If you work with the opinion leaders, there is a good chance that the community will decide firesafe is a good idea. If you don't, there is a very good chance that the decision will go against you.

Opinion leaders are people who can influence how other people feel. There are several techniques for identifying opinion leaders. One of them is pretty simple. On the Hayfork fire, we identified key communicators and opinion leaders in less than six hours and had a public meeting. I wouldn't advise that as a way to do it on a typical basis; you usually want to be more careful in sorting out the key communicators. You can use a technique called sociometry, or you can use people in the community who are experts and can tell you who the people are who might influence opinions there. If you get one expert to give you a list, another expert to give you a list, and another expert to give you a list, you can then compare lists; people who show up on all three lists are probably influential. Officers of clubs and other service organizations make good experts. Validate that with some other people, and you've got a rough-cut idea of who the opinion leaders are. Those are people you've got to work with.

At the persuasion stage, interpersonal media should be used; there's nothing you can do with the mass media. This doesn't mean you going out and talking to people, although you need to talk to the opinion leaders in person. At this stage, people talk to their opinion leaders; the opinion leaders need to have the right idea. You spend your time with those opinion leaders; when other people contact them, they'll be able to say, "Yes, that's a good idea."

Slide 5: (Decision) At the decision stage, people make a commitment. You might have to do some things to help out. They might need low interest rate loans. You may need to provide lists of horticulturists or landscape architects who can provide adequate designs. There are many things that people don't really know how to handle at this point. One of the things we found in promoting firesafe was that we ended with brush and debris piled up around houses. Not exactly a firesafe situation. One of the things we had to do right away was to get that brush to a safe place to store it. We know in much of California that when people decide to adopt firesafe practices, they clear their brush, then in the spring they rush to get it burned before fire permits are required, and we end up with escaped debris burns. Often, even after people are persuaded that a new idea or thing is good and feasible, they stall at the decision stage. This is especially true of preventative innovations such as firesafe.

Slide 6: (Implementation) Here's where people have to get it done. Are there people they can hire to do clearing? In Hayfork, we had some elderly people. There was no way they were going to go out and clear around their property. They didn't have the ability to do that. They didn't have the tools to do that. We worked with people from the high school who organized students to clear property for the elders. Implementation is not something that automatically happens.

Slide 7: (Confirmation) At this stage, you can use both interpersonal message and mass media; they're still going to be checking with their opinion leaders. You can use mass media to some effect by describing benefits, houses that have been saved, other kinds of benefits that people can relate to. You can use public meetings; you can provide awards; there are all kinds of things you can do to enhance the idea in people's minds that firesafe was a good idea.

Slide 8: (Crisis) Now, the kinds of things we're dealing with are called preventative innovations. They're the same kinds of things as wearing seat belts, motorcycle helmets, getting a chest X-ray, having your teeth checked, all those things you put off. We find that for preventative innovations, crises are a very good time to get people started. We're talking about getting to a specific neighborhood that has a fire department nearby and that's got a hazard that's identifiable. Any kind of fire crisis, whether it's in the community or nearby can be enough to get people's attention and allow you to move them forward in the decision-making process.

Now, the crisis only has an affect for a little while. I think this year's California fires have a tremendous effect right now. In Hayfork, it certainly did. We went out and started doing a little clearing around a place as a demonstration, and the neighborhood started coming out and watering down their houses, they were sure the fire was coming into town. It probably would have been a good idea not to wear our nomax as we were doing that. Anyway, the awareness was there, and it didn't take long to go through the stages between persuasion, decision, and action. It moved to action pretty fast. You can take advantage of those things, but next year, it's going to be harder and the next year, this year's fires won't have much effect at all in terms of getting people to move through the decision process.

Let me summarize some of the main points. First you need to adopt the receiver's orientation to communication about firesafe and give up thinking like a source. You won't be successful in communicating the firesafe idea to people in the urban/wildland interface unless you match your messages to the kinds of things those people are looking for, put the messages in the media that they use, and put it there during the times when then are looking for that kind of information. The receivers, like trout, are in control of the situation; promoters and fly-fishers are not the ones in charge. In communication, as in fly-fishing, success depends on your ability to "match the hatch." Here are some things to keep in mind:

1. Focus your promotion efforts on local neighborhoods or communities. Avoid total reliance on messages broadcast to the public at large.
2. Before you begin, find out about the mass media and informal communication channels available to and used by the people in the neighborhoods you have targeted.
3. Evaluate the firesafe "technology" as it is perceived by people you want to adopt it. How do they see it in terms of compatibility with their values and beliefs? What relative advantages and disadvantages do they see if they adopt? How complex do they feel implementing or understanding firesafe is? Do they feel the idea can be modified to their own particular situation successfully? Can it be tried out a little at a time? Can they easily see the benefits of adopting? Can people tell when others have adopted?
4. Given the results of your "technology assessment," modify the firesafe idea so that it is acceptable and desirable to the people who will be asked to adopt. It is much easier to change the characteristics of a thing like firesafe than to change people's tastes, preferences, and attitudes.
5. Use different communication channels and emphasize different characteristics of firesafe at different times during the process of decision making.
    a. Mass media are good at the awareness stage. Take advantage of fires that occur near the community to show how fire behaves and how firesafe will help save things that are valuable to them. Emphasize the positive--show houses that were saved because the right things were done instead of houses that were lost because the right things were *not* done.
    b. Interpersonal communication among people in the neighborhood and between people and their opinion leaders is the most important, almost the only important communication at the persuasion stage. People will be most concerned about the compatibility and relative advantage of firesafe at this time.
    c. At the decision stage, both interpersonal and mass media can be used effectively. Both should be used. At this stage and during implementation, people will need "how to do it" and "where to get it" information.
    d. Don't forget the confirmation stage. Especially with something like this, it is necessary to continue to reinforce the decision to adopt. Use mass media demonstrating the wisdom of adopting firesafe by telling success stories. Work with local opinion leaders one on one.
6. If you want to know more about the ideas behind these suggestions, read this book and a very recent text in marketing. I have used ideas from Rogers to a great extent in preparing this presentation.

    Rogers, Everett M. 1983. *Diffusion of Innovations*. (3rd ed) New York: The Free Press.

SESSION 4--WORKSHOPS

James F. Mann, Moderator
Director, Aviation and Fire Management
Northern Region, Forest Service
U.S. Department of Agriculture
Missoula, Montana

Dixie Dies, Logistics Coordinator
Support Service Supervisor
Beaverhead National Forest, Forest Service
U.S. Department of Agriculture
Dillon, Montana

HELPING HOMEOWNERS AND DEVELOPERS UNDERSTAND WILDLAND RESIDENTIAL DEVELOPMENT PROBLEMS

Notes from Workshop No. 1
Workshop Leader: Bob Lee
Facilitator: Ginny Tribe

The overall purpose of this workshop was to gain a better understanding of homeowners, developers, fire service officials, and elected officials. Also, how understanding ourselves in our various professional roles is equally important to understanding how homeowners and developers can come to grips with wildland residential problems.

Workshop participants were divided into four groups, and each addressed a different theme by identifying problems or obstacles and solutions as follows:

GROUP 1: HOMEOWNERS

The purpose of this group was to give a better understanding of how developers and fire agencies, by giving quality information, can motivate homeowners to protect their homes and at the same time prevent fires.

The following are problems dealing with homeowners and solutions.

1. Life saving communications to the homeowner can change behavior through:

    a. Schools/children
    b. Posters
    c. Community events
    d. Personal contact
    e. T.V. spots/media support
    f. Detail for informed decision

2. Early awareness of fire hazard will affect decision process:

    a. Statutory recognition of problem
    b. Subdivision review process
    c. Purchase of property - person advised of conditions
    d. Actual building processes

3. Motivational factors:

    a. Personal
    b. Economic
    c. Community

4. Pride of ownership:

    a. Compliment positive actions/recognition
    b. Show examples of "good silvicultural practices" which enhance value and reduce fire hazard
    c. Competitions and recognition by agencies

5. Specific documentation of money savings for fire hazard reduction:

    a. Insurance
    b. Resale value documentation
    c. Identify items you do not want to lose
    d. Clarify the non-replaceables

6. Identify community goals:

    a. Reduction of ISO rating
    b. Fire training:
        1. Escape plans (individual community)
        2. Space and vegetation management for aesthetic/landscaping/fuel management
    c. Community action manpower mobilization
    d. Community "fire organization"

7. Counteract denial (there is no problem) with information:

    a. Identify credible referral source
    b. Focus on positive by identifying successes elsewhere

8. Communication skills:

    a. Problem manager
    b. School level - intervention
    c. Inservice management and communication skills
    d. Legislative or statutory framework for related hazard reduction/mitigation

The major themes were to inform the property owner (choices), give demonstrations, and communication skills.

Workshop Report developed at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Bob Lee is a Professor, University of Washington, Seattle, WA.

Ginny Tribe is Public Affairs Specialist, Lolo National Forest, Missoula, MT.

GROUP 2: KNOWING OURSELVES

The purpose of this group was to better understand ourselves and how we, in whatever role we play, as homeowners or agency people, are part of the problem and hence part of the solution.

1. Obstacle: Local acceptability of prescribed burning within the community.

Solutions:

a. Good smoke management
b. Awareness of different types of smoke
c. Provide services, technical expertise
d. Liability
e. Cost versus mechanical versus chemical

2. Obstacle: Agencies acceptability of prescribed burning within the community.

Solutions:

a. Concepts behind why to burn
b. Training, technology transfer on how to burn
c. When to burn, smoke management, air quality
d. Multi-year fire planning and budgeting
e. Education, public support for program
f. Liability (Florida, Chapparal Management)

3. Obstacle: Country living is different. Homeowner is on their own. "Welcome Wagon" packages from fire department.

Solutions:

a. Training, work with local county officials, real estate, banks, insurance
b. Restrictions on deed-restrictive covenant
c. People within small area, community restrict or do not restrict themselves
d. Fire service user rates - incentive to reduce rates by doing certain things to home or property

4. Obstacle: We try to dictate to independent people.

Solutions:

a. Good persuasive communications - make them have ownership in the ideas
b. "Carrot sticks" first, enforcement second
c. Training of fire service personnel
d. Positive strokes for those homeowners doing good

5. Obstacle: Perceiving the solution as coming from the outside.

Solutions:

a. Encourage employees/officials to be part of the community
b. Determine and publicly identify who is

6. Obstacle: Leaders do not understand our purpose here (reference Melcher speech).

Solutions:

a. Involvement of homeowner groups, staff people, officials in educational functions, workshops, symposiums
b. Lobby officials by state staff officials
c. Report successful communities to legislator
d. Send letters to legislators, county officials

7. Obstacle: Sometimes need a crisis (for example, house next door to burn), to get homeowners' attention.

Solutions:

a. We may have public's attention, enough houses have been burned
b. More awareness, education
c. Local fire services need to agree and present a unified/cooperative answer

8. Obstacle: How safe is safe? Where do you need to stop on fire-safe measures?

Solutions:

a. Assemble knowledge from grass roots
b. Photo-guides, risk source ratings
c. Cost and New Value Charge (C&NVC)
d. Reduce uncertainty to point where the risks are known

GROUP 3: PLANNING CONSULTANTS

The purpose of this group was to further a better understanding of developers, and the process by which regulations are formulated and implemented.

1. Negative Influence: Different objectives.

Solutions:

a. Communicating and learning anothers objectives

2. Negative Influence: Lack of understanding of fire management/developers objectives.

Solutions:

a. Define common objectives

3. Negative Influence: Short run economic considerations - 1) cost of capital facilities, 2) water, 3) access, 4) site development, 5) construction techniques, 6) vegetation modification.

Solutions:

a. Negotiation to a common solution/standards

4. Negative Influence: Bad past experience.

Solutions

a. Recognize your own biases

5. Negative Influence: Increase risk to the resource with increased use.

Solutions:

a. Through use of regulations (site standards) and education (initial and continuing education)

6. Negative Influence: Red tape.

Solutions:

a. Streamline process via knowledge of system
b. Uniform standards for submittals

7. Negative Influence: Lack of incentives to cooperate/administrative inflexibility.

Solutions:

a. Is a fact of life

8. Negative Influence: Lack of support between agencies and governing bodies and lack of authority in the political process.

Solutions:

a. Better communication between agencies

9. Negative Influence: Lack of authority to make decisions at initial contact level.

Solutions:

a. Delegate authority and understanding own authority

10. Negative Influence: Time constraints relative to decision making and work load constraints.

Solutions:

a. Adopt reasonable time constraints

11. Negative Influence: Curriculums do not teach new technology, and lack of curriculum on communication and negotiation.

Solutions:

a. Provide more opportunities for relevant education in communication, negotiation, in new technology (make your needs known)

12. Negative Influence: Economics of providing fire suppression to residential development.

Solutions:

a. Innovative financing methods (working with the developer)

13. Negative Influence: Lack of interest in continuing education.

Solutions:

a. Economic incentives for continuing education

14. Negative Influence: Lack of system for initial communication between developers and agencies.

Solutions:

a. Set up a system

15. Negative Influence: Lack of consistent standards.

Solutions:

a. Adopt and hold to consistent standards

16. Negative Influence: Concerns of special interest groups and precedent problem.

Solutions:

a. Realize they are there.

GROUP 4: AGENCIES

The purpose of this group was to better develop an understanding of fire service agencies and how they can contribute to solutions to the residential wildfire problem.

1. Problem: Economics - 1) expensive to remodel, 2) insurance disparity, 3) developer - short term planning.

Solutions:

a. Tax incentives
b. Loan incentives for fire safety features

2. Problem: Lack of agency cooperation.

Solutions:

a. Continue further interagency involvement

3. Problem: Media misinformation.

Solutions:

a. Communication

   1. Agencies educate media
   2. Tailored to "target" group (for example, different homeowner groups, developer groups, etc.)

4. Problem: Lack of agency understanding of culture tradition.

Solutions:

a. Agencies understanding local situation

HOW TO COMMUNICATE THE WILDLAND RESIDENTIAL FIRE PROBLEM TO POLITICAL LEADERS

Notes from Workshop No. 2
Workshop Leader: Gary Severson
Facilitator: Sandy Matheny

I. Identifying Barriers to Effective Communications with Political Leaders

A. General Barriers

1. Lack of knowledge/understanding
2. Lack of priorities/time/dollars
3. Poor credibility/lack of trust
4. Unwilling to deal with the issues
5. Resistance to agency input
6. Lack of adequate funding
7. Resistance to agency interference
8. Pro-economic development - Resistance to impairing regulations
9. Avoid conflict
10. Lip service
11. Constant change in elected officials
12. Don't know individuals
13. Not interested in unpopular issues
14. Technical jargon
15. Not in the network - don't participate
16. Influenced by special interest groups
17. Don't know protocol
18. Lack of trust
19. Change in elected officials
20. Shortage of money
21. Knowledge of the issues
22. Competition for funds (police versus fire)
23. We (firemen) don't always do "homework"
24. Time and scheduling
25. Insufficient preparation or report time
26. Personal agendas
27. Many diverse constituents
28. Availability of professional staff
29. Personality conflicts
30. Conflict of interest
31. "Fox guarding the hen house"
32. "My mind is made up, don't confuse me with the facts"
33. Obtaining approval of supervisor to approach political leaders
34. Time, energy, money to organize program to present to political leaders
35. Minority viewpoint does little to create pro-active posture from political representative or entity
36. Continuity among multiple jurisdictions
37. Identification of political leaders with responsibility - "whom do you address?"

Workshop Report developed at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Gary Severson is President, Dynamic Horizons, Evergreen, CO.

Sandy Matheny, Idaho Panhandle National Forests, Coeur d'Alene, ID.

38. Time constraints, primarily theirs
39. Differences in priorities, limited resources, money, etc.
40. Pressure groups with adversary agendas
41. Lack of consensus among all players
42. Lack of coordinated communication between agencies and lawmakers
43. Political terms
44. Technical expertise
45. Time
46. Accessibility
47. Issue priority
48. Competition for money
49. Existing current fire laws
50. Time involved in political process
51. Campaign funding
52. Public opinions
53. Lack of trust
54. Protocol
55. Personality conflicts
56. Agency lacking political savvy
57. Political leaders (county commissioners) having faith/trust in judgment of Federal employees that a problem does exist
58. Political leaders not supportive of exiting laws/regulations regarding fire due to political pressure (contractors, developers)
59. Dissimilar agendas
60. Issues: Statewide versus Regional
61. Can we show financial aid (small community)?
62. Small amount of locals are supportive
63. Understand/believe that a problem does exist before an incident occurs
64. Jurisdiction (turf)
65. Over-scheduled politicians
66. Lack of access
67. Supportive groups (who - rural, VFD, etc?)
68. Anti-government and State feeling
69. Financial - will it cost?
70. Jargon (define)
71. Travel - cost to visit meetings
72. Is there organizational support?
73. Lack of understanding of local politics
74. Party politics (overrides)
75. Agency politics
76. Being compromised
77. Dislike of politicians
78. Tendency to delegate authority

B. Priority Barriers

1. Broken communications (see solution II-A)
2. Lack of trust (see solution II-A)
3. Non-interest (see solution II-B)
4. Lack of awareness (see solution II-B)
5. Non-election issues (see solution II-B)
6. Non-similar agendas (see solution II-B)
7. Lack of awareness of agency policy (see solution II-C)
8. Misperception of agency procedure (two-way) (see solution II-C)
9. Anti-agency attitude (see solution II-C)
10. Personalities (see solution II-D)
11. Old battles (see solution II-D)
12. Preconceived ideas how to do things (see solution II-D)
13. Logistics - funds, time, solutions (see solution II-E)
14. Political pressures caused by constituents, special interest groups and the media (see solution II-F)

15. Financial constraints (see solution II-G)

    a. Any costs - they are not interested in the project

    b. Project may not fit within their priority

16. Lack of trust in fire officials (see solution II-H)

17. Their time - my time; matching calendars, prework, meeting length (see solution II-I)

18. Inform them on the problem (see solution II-J)

    a. Predetermined attitudes

    b. Resistance to change

19. Lack of knowledge/understanding

20. Lack of time

21. Not interested or not our problem

22. Poor credibility between agencies and political leaders

23. Higher priority issues than yours

24. Many diverse constituents

25. Conflict of interest

26. Knowledge of the issues

27. Firemen (foresters) don't do "homework"

28. Not interested in unpopular issues

29. Time, energy and money to organize program to present to political leaders (see solution II-V)

30. Minority viewpoint does little to create pro-active posture from political representative or entity (see solution II-W)

31. Time constraints primarily theirs (see solution II-X)

32. Differences in priorities, limited resources, money, etc. (see solution II-V, W, X)

33. Pressure groups with adversary agendas (see solution II-Y)

34. Lack of consensus among all players (see solution II-Y)

35. Lack of coordinated communication by agencies (see solution II-Z)

36. Issue priority (see solution II-Z)

37. Competition for money (see solution II-Z)

38. Time involved in political process (see solution II-Z)

39. Anti-government and State feelings (see solution II-AA)

40. Trust (see solution II-BB)

41. Understanding/believing a problem exists (see solution II-CC)

42. Turf (see solution II-DD)

43. Financial (see solution II-EE)

II. Identifying Ways to Develop Effective Communications with Political Leaders

A. Be honest, patient. Build on relationship in short exposures. Admit mistakes and/or limitations of self or agency.

B. Build early broad based coalition. Look for common ground. Develop concise fact case. Be patient. Develop the community networkers or key contacts.

C. Create a two-way understanding of policy, procedures, and responsibilities early.

D. Be alert that these may exist and try to avoid them. Pick out people you can deal with and work with them.

E. Be concise. Provide suggested solutions and alternatives, if possible.

F. Identification and education of groups. Anticipate groups concerns/questions. Involve interest groups in the solution. Take personal time in educating media representatives. Use an integrated approach that involves all players. Build consensus.

G. Be able to explain cost/benefits. Be able to explain trade-offs. Know what the project is before trying to solve financing needs. Use volunteers. Research different types of grants, gifts, etc. Involve other persons/agencies.

H. Maintain good communication. Do not wait until you have a problem to develop a relationship. Admit mistakes. Try to find/talk with a person who knows the political leader (educate yourself). Do what you promise to do. Tell leader that you (your group) is willing to do the work.

I. Scheduling a meeting in advance to meet their needs. Keep meeting short. Be flexible to accomodate their changing time needs.

J. Be prepared for meeting.

   1. State problem that this political leader can solve - use visuals

   2. Tell why it is a problem

   3. Identify possible solutions

   4. Provide recommended approach

K. With a united group build and maintain credibility with elected officials.

L. Provide information, education, examples.

M. Provide options to solve problems (pluses and minuses).

N. Suggest process of logical implementation.

O. Supply support and assistance.

P. Inventory and identify where support exists/does not exist.

Q. Educate and inform public.

R. Build and consolidate support.

S. Develop briefing package.

T. Pick champions to help out.

U. Learn procedures, process, and key people.

V. Set internal organization priorities.

W. Build strong vocal coalitions with grass roots support prior to political contact.

X. Information to political leaders in advance of becoming a political issue.

   1. Concise information

   2. Precise solutions

Y. Identify these groups.

   1. Communicate

   2. Reach consensus (compromise)

   3. Meet on their turf

Z. Interagency cooperation and coordination.

   1. Define problem

   2. Develop solutions

   3. Develop plan

AA. Identify feelings and go to grass roots and let them go to local government for you. Gain support of some other local agency.

BB. Avoid 49% of non-interested. Be positive to gain allies.

CC. Clearly identify concern. Then go with education. Use a coalition.

DD. Identify problem clearly. Determine boundaries.

EE. Do your homework. Have alternate choices. Look at risk factors for each solution. Show benefits. Be sure and prioritize.

HOW TO COMMUNICATE ABOUT THE WILDLAND RESIDENTIAL FIRE PROBLEM WITH HOMEOWNER GROUPS

Notes from Workshop No. 3
Workshop Leader: Ron Hodgson
Facilitator: Judy Norgaard

The most important result of this workshop was the insight gained into the kinds of things that might prevent effective communication between homeowners and the fire services and those that might make it easier, if taken advantage of. The summary will, we hope, be used by researchers to identify areas where we need to know more and by managers to establish communication goals and objectives.

Groups of workshop participants have considered characteristics of the fire services, homeowners, and the fire safe practices themselves. The situation faced by homeowners and the fire services before, during, and after the fire were evaluated to specifically suggest communication opportunities and difficulties.

GROUP 1

The characteristics of the fire services and their situations that make it difficult to communicate with homeowners about wildfire and fire safe practices before, during, and after a fire.

Before a fire

Regulatory controls.

Economics - Manpower/Agency
Cost/Homeowner

Environmental handicaps.

Fire service attitudes

Dream Filter System - People find it hard to deal with the reality of fire. "It can't happen to me" syndrome. Insurance coverage helps to justify.

No Common Bond - "Neighborhoodism" prevents common bonding between homeowners and fire service.

Jurisdiction - "Who should" attitude.

Politics.

Residential types - Native versus transient.

No past history of problem.

During a fire

No media.

Fire service is preoccupied with fire suppression.

Homeowners are not receptive to communication during holocaust.

Homeowners receiving information from mass media are often overwhelmed with sensationalism.

No public relations department to handle inquiries.

Absentees.

Lack of qualifications and/or equipment.

Homeowners lack understanding of qualifications and/or equipment.

Agency responsibilities and priorities.

After a fire

Fire service is busy defending suppression actions.

Nature of homeowners emotions - Armchair "Inciden Commanders".

Litigation - Cannot discuss with fire service, peers, etc. Almost like Court "Gag Order".

Credibility.

Media subjectivity.

Identification of whom to talk to. Agency, opinion leaders, etc.

Workshop Report developed at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Ron Hodgson is a Professor, California State University, Chico, CA.

Judy Norgaard is Public Affairs Specialist, U.S. Department of Agriculture, Forest Service, Washington, DC.

Hidden alligators - Local versus out-of-area overhead team.

Who does rehabilitation?

GROUP 2

The characteristics of the fire services and their situations that make it easy to communicate with homeowners about wildfire and fire safe practices before, during, and after a fire.

They are perceived as helpers. They save lives and property and rescue cats. (Before, during, and after fire.)

Fire service personnel are "regular people". They have a lot in common. They're a neighbor. (Before, during, and after.)

They have technical credibility through experience and knowledge. (Before, during, and after.)

They have personal credibility (Before, during.)

They have high visibility. (Before, during after.)

They have a good image. (Before, during, after.)

They are generally dealing with people in positions of authority. (During, after.)

The service personnel represent the lowest level of a Government entity. (Before, during, after.)

Homeowners' fear of fire and lack of knowledge allow easier communications with fire service personnel. (Before, during, after.)

Current events - Actions speak loud during or immediately after fire. (During, after.)

When economy is low people will tend to be more protective of belongings. (Before.)

Established organizations, equipment, and techniques used allow for better communications. (Before, during, after.)

Fire services have something to gain - a reward system. (Before, during, after.)

Fire service personnel are deservedly perceived to be motivated and dedicated. (Before, during, after.)

Playing on human tragedy tends to open lines of communication. (Before, during, after.)

Negative/positive. (Sometimes before, during, after.)

GROUP 3

The characteristics of the homeowners and their situations that make it difficult to communicate about wildfire and fire-safe practices before, during, and after a fire.

Fire service diversification. (Before, after.)

Homeowners' priorities. (Before, after.)

Outdated codes. Yesterday's regulations do not meet today's standards and today's standards will be outdated tomorrow. (Before, after.)

Migration to and from area inhibits better communications. (Before, during, after.)

Fear of regulations - more economic/personal choice than aesthetic. (Before, during, after.)

Bending the codes. "Rules are made to be broken". What guidelines are to be followed? Is nothing sacred? (Before.)

Natural groupings. Associations, absentees, etc. (Before.)

Diversity. Should they bless or damn the covenants? Based on economics. (Before, after.)

Disorganization. Who should do what, when, and how? Causes chaos. (Before, during, after.)

Silent (deaf) bureaucracy. (Before, during, after.)

Unfamiliarity with language, jargon. (Before, during, after.)

Coherent approach by fire service. (Before, during, after.)

Rumor control, or lack of. (Before, during, after, and on and on and on...)

"Big Brother" syndrome. (Before, during, after.)

Preconceptions - any or all. (Before, during after.)

Additional Comments

How can safety be taught when homeowners are forced to leave scene during fire? They will demand to stay regardless of knowledge about fire hazards and/or safety. Double-edged sword.

GROUP 4

The characteristics of the homeowners and their situations that make it easy to communicate about wildfire and fire safe practices before, during, and after a fire.

Before a fire

Common bonds: Survival - (a) life; (b) investment; (c) aesthetics (prevent fire to preserve).

Feelings of control, independence - (a) avoid intervention; (b) exploit self-reliance; (c) form own Homeowners' group.

Sense of community - (a) peer pressure on irresponsible homeowners; (b) "same boat" attitude; (c) pride in neighborhood.

Exploit leadership inherent in the community; use as catalyst.

Children play primary role in changing adult behavior. Reach children.

Choices: Appeal to income and ability levels in the community with (a) private consultants; (b) Government advice - use permit property users - they're used to dealing with government; (c) community help, etc.

Exploit homogeneity of community, that is, the approaches must fit the community's nature.

Nature of ecosystem - communication based on the type of fire in the specific area.

Education.

During a fire

Survival - opens minds toward better communications.

Psychological - community reaction, education applied, fuel removal as fire progresses.

Stress enhances motivation.

After

Experience - evaluation: (a) prevention practices that work or need modification; (b) being open to learning about fire ecology - post-fire succession and species to re-introduce; (c) motivation - increased sense of community, focused interest due to common experience; (d) home destroyed - insurance money to rebuild - open to building fire safe structures.

Additional Comments

People don't perceive "natural events" until they are the victim.

Learn by watching.

Incensed by the idea that adults don't want to learn. There are many ways to accomplish learning. People can't help but learn, short of being brain dead, but knowledge should be applied. In short, adults don't change easily.

Represent innovators.

"Multiplier effect" - use to educate adults,

People are receptive and willing to promote.

GROUP 5

The characteristics of fire-safe practices themselves that make it difficult to promote them.

Fuel modification

Altering the "natural beauty".

Conflict with perception of what should be.

How do you get rid of it?

Disposal conflicts with regulations.

Cost.

Resistance to authority.

"Big Brother" syndrome.

Suppression Tactics

Homes - Direct.

Wildland - Indirect.

Public asks why.

Roof Materials

Covenants.

Architectural ego.

Public perception of aesthetics (elected officials).

Cost of removal of slash, etc.

Industry lobby.

Social Status.

Site Selection of Planning

Developer won't accept fact that there is a haza and/or cost.

Fire services too late into the process.

Local government does not realize problem - haza and fire behavior.

30/30 syndrome.

Vested interest of developers.

Access

Cost.

Misconception of what is aesthetic.

Takes wilderness out.

Encourages transient visitors.

"Crime rate" goes up.

Water Supply

Cost.

Fire Safe Education

Want city protection in rural atmosphere.

Jargon ("fuel", "Ecosystem", etc.)

Time constraints and money.

Emphasis is on suppression rather than education.

Complacency (apathy) - important concern.

Media gives wrong message.

Real estate industry is not in tune to problems.

Public lacks perception of the "unnatural" fuel situation.

Additional comments

False advertising after the fire. Very susceptible to fraudulent claims.

Exploitation.

It's relatively easy to get support and/or man-power through Homeowners' meetings. Follow up with handouts; hands-on material to put information into practice.

GROUP 6

The characteristics of fire-safe practices themselves that make it easy to promote them.

Personally cost-effective, if practiced.

Personal safety.

Enhances resale value of property.

Owner/occupant liability, if don't comply.

Perceptions of being logical.

Perception of social acceptability, follow neighbors' lead.

Perceptions of aesthetics, over-doing it.

Safety of mementos, belongings.

Feeling of inner comfort, doing everything possible.

Satisfaction of being in compliance.

Synergistic benefits of effects. Each one enhances itself. Some can have more than a single effect.

Economics remuneration from following safe practices.

Additional comments

Sometimes imagery is tarnished through perception, based on previous opinions.

USING WILDLAND RESIDENTIAL STANDARDS, LAWS, AND REGULATIONS FOR PROTECTION NOW AND IN THE FUTURE

Notes from Workshop No. 4
Workshop Leader: Gary Tokle
Facilitator: Ed Heilman

This workshop was conducted in three parts: 1) a panel discussion consisting of Dick Bacon, Tim Murphy, Rich Schell, Jo Bridges, and Don Wood, 2) a question, answer, and concern session, and 3) identification of five key issues.

PANEL DISCUSSION

Dick Bacon, USFS Fire Planner, Washington, D.C.

Urban interface is the most complex political area we work in and a very sensitive one. We need to take a look at the long-term objectives as a partnership.

We need to focus on the correct objectives:

- Minimize loss of life and property
- Minimize cost of fire protection and losses
- Minimize drain on our equipment
- Community standpoint

Our objective is to "develop defensible homes and defensible property. It is not to eliminate shake and shingle roofs".

Basic Assumptions:

1. Regulations developed at the Federal and State Government level create problems. People's perception is that personal rights are being taken away. One alternative would be to work with the insurance companies.

2. If the local community develops the regulations, they feel their rights are protected. Most people want a choice.

3. We can't develop regulations at the National or State level that will cover all situations.

Three categories of rules when developing regulations:

1. Adjacent property owners - need to be sensitive to their concerns

2. Work with developers - cost effective/reasonable

3. Work with residential homeowners

Responsibilities:

As consultants or advisors, we need to facilitate and offer reasonable alternative solutions. We need to help the public understand the economic implications of regulations. And we need to provide a framework to evaluate various strategies.

Most of us believe regulations are necessary; we have the technical knowledge, now we just need to go to work.

Recommendations:

1. Support NFPA effort to develop national standards and guidelines.

2. Encourage each state to generate standards and guidelines.

3. Provide assistance to states - Coop Fire Protection.

4. Develop regional or national evaluation system to evaluate the needs of the communities.

5. Need local studies in 2-3 years.

Tim Murphy, Chief, Division of Fire, Department of State Lands, Missoula, MT.

In order to make regulations and standards, first we need to understand the system and the components. There are four major components:

1. The Public - most people move to these areas to get away from people, they want to "get back to nature." Most don't understand the problems and the risks. They feel secure with their local fire protection agency.

Workshop Report developed at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Gary Tokle is Senior Fire Service Specialist, National Fire Protection Association, Quincy, MA.

Ed Heilman, International Fire Council, Missoula, MT.

2. The Developers and Planners - most convey the message that wood construction is more natural, minimum improvements preserve the natural setting, seclusion and privacy take precedence.

3. The Fire Service - in many cases doesn't fully understand the problem, isn't willing to implement certain measures and often reinvents the wheel.

To effect change, the fire service must complete fire hazard and risk analyses, maximize prevention and public education programs, develop interagency fire pre-plans, maximize interagency cooperation and coordination, and send a uniform message to the public.

4. The Lawmakers, Regulators, and the Courts - at local, state, and national level, need to look into fire insurance rates that reflect actual probability of destruction by fire, interest rates that encourage fire-safe design and construction, tax incentives, tax penalties, cost share. We need to encourage legislation.

A standard is what is acceptable. We need standards to know where we are going and how to get there. Adoption of a basic set of standards by NFPA is a foundation for local standards, regulations, statutes and minimum protection requirements. NFPA needs to prepare and finalize such a standard. With a national guideline, local authorities can establish their operations and control through implementation of general plans, zoning and developmental plans.

Through the above four inter-related components, we can effect change through education, engineering and enforcement to achieve excellence within the Fire Service and the protection of homes from wildfire.

Rich Schell, California Department of Forestry and Fire Protection, Sacramento, California.

Mr. Schell shared California's approach with the group, commenting that there are different social and political pressures and there is no single approach.

He gave a chronological presentation from 1962 to 1987:

1962 - The California Department of Forestry and Fire Protection (CDF) publicized the problem of protection in the wildland/urban interface areas.

1965 - First step to develop and adopt fire safety publication. Discussed need for fire protection planning, identifying hazardous fire areas. Proposed minimum fire safety requirements for subdivisions and developments.

1967 - Passed into law a series of regulations related to perimeter encroachment into wildlands, clearance around structures, and regulations concerning campfires, powerlines, small engines, etc.

1971 - State moved into planning process. Provided guidance to local government. Major fires gave opportunities to implement. Many counties were inconsistent, some non-compliant, and others very stringent.

1980 - USFS and CDF updated publication to optimum standards rather than minimum standards.

1981 - State legislation required CDF to identify fire hazard severity zones that specify the potential intensity of wildfires that threaten to destroy resources, life, or property. Fire resistant roofing regulations.

1984 - FS and CDF proposed to insurance industry an incentive program with homeowners. Reduced rates were flatly refused by the insurance industry.

1987 - CDF and California Board of Forestry introduced legislation to require contractors and developers to incorporate self-protection measures in wildlands whether it be residences, commercial, or camps.

Two other programs Mr. Schell mentioned included a cost share vegetative management program and a series of workshops in California co-sponsored by CDF and USFS to develop a framework to implement defensible space in terms of Fire Safety Program.

Jo Bridges, Community Planner, USFS, San Bernardino, California

Ms. Bridges spoke of a success story which was born out of the Panorama Fire in San Bernardino. Following the fire, the USFS did a feasibility study of greenbelt options running the length of the county. They looked at all aspects and involved 14 other agencies. It was determined that the traditional greenbelt (golf courses, parks, agriculture land) was not appropriate for most of the area.

Recommendation of the feasibility study was to continue working together in two areas:

1. Public information area

2. Develop standards that would apply across jurisdiction lines

They have worked out the above two areas and have delineated hazard zones. Standards have been implemented by the city and county.

However, the county adopted the ordinances December, 1986 - 6 years after the Panorama Fire, about 25 years too late. The area is already 75 percent built out. We can't sit and wait for disaster to happen.

There are two areas that need emphasis in the future:

1. Public involvement/awareness

2. Involvement of USFS. The involvement of the FS in this case was unusual. The FS is usually reluctant to get involved in traditional local jurisdiction. Would like to see a continuance of this cooperation.

Don Wood, Consulting Forester, Corvallis, Montana

Mr. Wood identified five points concerning people living in the wildland/urban interface areas:

1. People move out to these areas because they like to solitude, they love wildlife, the scenery, the wilderness and the independence and freedom. They are not convinced there is a problem from fire.

2. Positive reinforcement is more effective than punishment.

3. We need to advertise, publicize and educate. No everyone perceives the problem in the same way.

4. People need to be introduced to the subject slowly. Allow the people to go through their own thought process. Allow them to think of solutions.

5. Homeowner involvement is the most important step. It allows the people to exercise their independence.

We need to find rational solutions rather than dictate unreasonable requirements.

KEY ISSUES

The group discussed a wide range of issues. They developed the following prioritized list of five key issues that need to be addressed:

1. Develop standards for identification, rating, and modification of wildland fuels for property protection, including provisions for long-term maintenance.

2. Develop long-term education and publicity programs to include the following audiences:

- property owners
- residents
- building and design professionals, including developers
- school programs
- fire fighters
- legislators
- local government

3. Develop subdivision and building design criteria for wildland/urban interface areas. These criteria should recognize differences between fuel conditions, be coordinated between agencies, and established at the lowest possible government level.

4. Develop incentives to encourage voluntary compliance with fire safety regulations and standards.

Examples:
- insurance incentives
- tax and assessment incentives
- incentives between levels of Government (that is, distribution of funds)

Coordinate effects of incentives between Government entities. As an example, when a credit is given for a type of improvement, that credit is not then offset by higher assessments.

5. Develop guidelines to involve residents and property owners in development and implementation of wildfire prevention standards.

COOPERATING WITH THE MEDIA TO PROMOTE FIRE MANAGEMENT IN WILDLAND RESIDENTIAL AREAS

Notes from Workshop No. 5
Workshop Leader: Jamie Haines
Facilitator: Steve Laursen

This workshop focused on using the media to transmit fire management information to the general public and urban/wildland interface homeowners. Two basic questions were addressed:

1. How do we best work with the media during an actual wildland fire crisis?

2. How do we best work with the media to communicate the need for homeowners to engage in fire prevention activities in wildland/urban interface developments?

SESSION I: FORMAL PRESENTATIONS

Four speakers presented their perspectives relative to the two basic questions:

Lori Sharn, Reporter for USA Today

Suzanne Lagoni, Communications Director for Montana Senator Max Baucus

Beth Horn, Staff Director for Information, USFS, R-1

Gladys Daines, Manager, Smokey Bear Program, USFS, Washington, DC

rief summaries of their presentations follow.

. Lori Sharn - National Perspective

Timeliness is critical. Today's news should be relayed today and get it right the first time.

A. Timeliness

  1. Need information as soon as possible

  2. 4 p.m. west is 7 p.m. east

B. Getting right information

  1. Give good specific information, recognizing "hot items". Call in immediate information; USA Today's phone number is 800-368-3024.

  2. Cultivate local contacts including Red Cross and homeowners affected (provide phone numbers).

  3. Press love advance on-hand material. Send it regularly. It may be used at a later time.

  4. Local news is good.

C. Be sure to do good advance work

  1. Where is the action (the fire and the firefighters)?

  2. Who should the press contact to get "good" information (desire to warn public)?

  3. What are the follow-up stories (days, years) that can be utilized by reporters?

II. Suzanne Lagoni - Regional Focus

  A. Discussed first fire she covered as a TV news anchor - Pattee Canyon Fire, July, 1977.

    1. Outlines problems from her perspective

      a. No film crew available

      b. 3:00 p.m. - only a few hours before she was to go on the air

      c. Wanted to pinpoint area of danger

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orkshop Report developed at the Symposium and orkshop on Protecting People and Homes from ildfire in the Interior West, Missoula, MT, ctober 6-8, 1987.

amie Haines is Director of Public Affairs and ublic Education, National Fire Protection ssociation, Quincy, MA.

teve Laursen is Forestry Specialist/Assistant rofessor, Montana State University, Bozeman, MT.

d. Should she go out or stay at the station - where would she get the best information?

e. She got the run-around from fire folks

f. Started getting calls from AP and national TV networks

g. She needed to get on-air reports and finally did

B. By the next fire, the situation was much better

1. Coordinated agency effort - firefighting and media relations

2. Stations now call when events occur

3. Hot lines established and phone numbers distributed in advance

4. News about bad fire seasons distributed early

5. One agency takes control for public information on each fire

C. You have to realize first that there are different types of media people

1. Radio - they need a fast report on what's going on

a. Number of houses burned

b. Evacuations

c. Public alerts needed

2. Newspaper -

a. Because of deadlines they may have more time

b. More space to go further into story

c. Looking for features and side bar articles

d. Because reporters may have been in area longer, they may be better informed

3. TV and news photographers -

a. Always need more pictures and video footage

b. Reporters probably better understand situation

c. Problems with young, inexperienced reporters can require providing more background

D. Media Relations

1. The more information you give, the more good the interview can do

a. Important to get to know reporters from all media factions

b. Develop an ongoing media plan--it should be complete but flexible (for example, know reporters, but be prepared for newcomers)

c. Ensure safety of reporters (especially inexperienced)

d. Maintain social contacts and talk on phone even and especially when fires aren't burning

E. Media Relations Facilitation

1. Provide photos or footage

2. Provide opportunity for media to get photos

3. Tenet - Media will get stories and photos--help them tell your story

F. Q: Isn't it wise to train your reporters? (There is a need for training reporters to keep down excitement when interviewing.)

A: Yes, a news desk should keep contact with reporters and stress the point to keep calm.

Q: Some difficulty in dealing with the press exists because of the difference between image and accurate portrayal of the situation--when a bad portrayal is shown, image is eroded.

A. A good media plan should help resolve that. Advance work between agency and media really helps.

Comment: Because of inexperience of reporters, it is often a good idea for the agency to set up briefings prior to fire season with reporters.

Comment: Getting information out is the responsibility of the agency--do it when you have time - outside the fire season.

III. Beth Horn - Establishing Media Plan

Start with the understanding that no matter how much you plan, you may not have time to carry out plans to the letter - be flexible.

A. Objectives of Information Officer (IO)

   1. Relieve pressure on other fire people

   2. Maintain a central place for media information

   3. Provide fire education/presentation information

   4. Bridge between press and public

   5. Accessible press center - phone lines (2) in/out

B. Media List

   1. Keep up-to-date with media within state/region

   2. Note deadlines and schedules

C. Media Relations

   1. Call early to establish press briefing schedule

   2. Allow lead time for reporters

   3. Provide "quick bite" for press who call in

   4. Keep an up-to-date list of "fire facts" for reference

   5. Have a set of maps - state, highway, and fire

   6. Be prepared to report expectations (prognosis) but don't give erroneous information!

D. Correct Information

   1. Visit fire boss and strategy sessions

   2. Make sure someone else in overhead is able to help with overflow of media

   3. Human interest stories should be provided (for example, story about firefighter for local newspaper)

   4. Provide stats about "airshow", "fireline", "chowline", etc.

E. Fire Information Plan - Pre-Crisis - Do in advance of fire season

   1. Media contacts, local officials, and emergency services - who will contact them and when

   2. Conduct education programs for people who might be affected by fire

F. Comment

   1. If you have photos or file tapes, offer these to the media

   2. Have statistical and other information at your fingertips

IV. Gladys Daines - Public Service

A. History

   1. The Smokey Bear Program has been around since 1942.

   2. Purpose - create and maintain public awareness

   3. Message is not that all forest fires are bad, it is that people can and should prevent wildfires

B. Developing a public service campaign

   1. Decide what focus will be and develop a plan including time needed for production, distribution, and placement

   2. Develop print public service ads

      a. Newspaper and magazines can use spots year around

      b. Radio uses mostly when it is fire season

   3. Develop a variety of PSA approaches to reach different audiences and tackle different problems

      a. Geographical strata

      b. Cultural strata

   4. Send out advertising kits

C. Placing your PSAs

   1. Have agency representatives go to media with kits

   2. Make sure your campaign is launched to cover all the problem areas

   3. Television and radio are interested in local PSAs with local information

      a. Do good job in producing

      b. Do good job in contacting

SESSION II: QUESTIONS, ANSWERS, AND COMMENTS

1. Comment: Session has concentrated on working with media during crisis. We need to develop

skills for working with media to promote fuel management/homesite protection as a necessary and regular activity.

2. Q: Talking about "giant" fires - small fires are a problem too - media doesn't cover small fires well. There was an incident where a reporter didn't know whose fire it was - went to residents. What should I do?

   A: Need to follow-up when erroneous information is published. Educate reporters on basics before crises. Also, provide demonstrations which illustrate all aspects of fire prevention/suppression.

3. Q: How does Smokey Bear Program deal with urban interface?

   A: A print PSA has a rake graphic to brush dry shrubs with supporting copy.

4. Q: Can we expect the newspapers to pick up on the prevention theme (is it news)?

   A: It depends on how it is presented - and on the type of media you're using:

   1. Graphics

   2. Short messages linked to related "newsy" story

   3. Build story around children

   4. Graphics feature on weather page.

5. Q: How do we get the media out to cover what we think are important events?

   A: Know what day of the week media have staff available.

   Involve media in planning process from "day one".

   Be aware that everyone is trying to use the media to disseminate their message. (Align yourself with other groups to reduce the number of folks approaching media.)

   Do some research on the problems - put together a report, then take it to the media. Volunteer the information.

   If you get one media person interested, you can get other media factions interested in their story.

6. Comment: Ally yourself with other groups to reduce the number of folks approaching media (such as the Red Cross and Salvation Army).

7. Comment: New design calls for Incident Commanders to do a lot of dealing with media. Incident Officers come to the Incident Commander rather than Plans Chief now.

8. Comment: RE: Information Planning

   a. Get plans in written form to be given to other people on fire overhead that come in (not in your unit).

   b. IOs from other areas are reading information off stat sheet and should be doing more to help educate the media to issues.

   c. You need to be sensitive to the needs of the reporter.

9. Comment:

   a. You have to get new news to the media. Consider different story ideas such as:

      - reforestation after fires
      - new computer technologies
      - new ICS
      - how can homeowners fire-proof their homes

10. Comment: Another branch of media is magazines - magazines need lots of lead time, but are often interested in longer stories.

11. Q: Scanners can allow media and residents to get to the scene before firefighters. How do we get media to help let John Q. know that they are endangering theirs and others' lives?

    A: Make it clear what your priorities are in a situation.

    Get hold of local media and show them situations.

    Media and firefighters have some motivation behind their professions - they just need to understand each other better.

FACING HARSH REALITIES: STRATEGIC CONSIDERATIONS NECESSARY TO OBTAIN CONSENSUS IN METHODS OF PROTECTING INTERFACE PROPERTIES

Notes from Workshop No. 6
Workshop Leader: John Marker
Facilitator: Troy Kurth

Workshop Objectives and Expectations: Participants identified five objectives and expectations:

1. Develop Concerns and Issues
2. Strategies to Support Concerns and Issues
3. Values at Risk: Resources versus Property
4. Wildland and Rural Capability
5. Share the "Tools" of Activity

Participants were then divided into subgroups addressing topical items through three structured goals.

Topical

Resident
Business/Commercial
Government
Fire Agencies
Resource Managers
Visitors

Structured Goals

1. Strategies to support concerns and issues, and share the "tools" of activity
2. Values at risk: resources versus property
3. Wildland and rural capability

The following is the collective professional opinion concerning issues and concerns that will have to be revealed in order to obtain consensus and methods of protecting interface properties:

THE RESIDENT

The primary concern is safety for self, family, and neighbor.

Safety for lives.

The need to be able to self-defense their property.

The lack of awareness for a potential of an incident, or self-denial of it ever happening.

Protect the natural beauty around the home.

Homeowners must build a defensible property.

There is a lack of education of the public about the fire environment.

Protection of pets and animals.

Residents could take an active role in fire defense of his property.

How to protect oneself from a neighbor's negligence.

Accomplish some coordinated community planning.

Recognition of building codes.

There is a lack of regulation imposed on the homeowner.

The wide range of codes and enforcement/ inspections causes problems.

An aversion to regulations by people who live in rural areas. The need to be free, live where they want, choose their own destiny--fire protection agencies can only protect property up to limits set by local people.

Residents do not have realistic expectations, that is, what the protection is, what the fire will do, etc.

Workshop Report developed at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

John Marker is Director, Public Affairs, U.S. Department of Agriculture, Forest Service, Portland, OR.

Troy Kurth is Forester, Aviation and Fire Management, U.S. Department of Agriculture, Forest Service, Missoula, MT.

Insurance rates are manipulated. Rates should be high enough to make people protect their home.

BUSINESS/COMMERCIAL

Protection of life.

Rules on insurance vary from State to State.

Safety and protection of property.

Commercial development is directly related to expansion in areas. This may be in direct conflict with required codes and regulations for fire safe environments.

Expectations of the business community for fire protection and services, that is, how quick might a volunteer fire department respond.

Protection of investments in properties including resource based properties and the resource supply.

Commercial base which is formed on natural resource use may be the cause of growth and expansion of the wildland rural/urban interface (ski lifts, lake shore recreation resorts, etc.).

Awareness of zoning codes.

GOVERNMENT

The Land Use Plans dictate what is happening or should happen.

Ordinances: There is a need for more sterilized control. Need to protect development from its own future self-destruction--shake roofs, for example. "The purchaser automatically assumes the development is safely built and located." Protection means--protection from not information about. There is a distinct lack of communication between the groups: the owner (purchaser) and the developer and the Fire Department. The real estate salesperson does not say: "Now you understand this place may burn down." The cart is before the horse: The residences are built before adequate roads, protection, other essential services are provided. (By who?)

A better definition of responsibilities through the various levels of Government is needed. Government officials must realize this issue is one of their problems.

The Government sometimes is forced to do unrealistic things, like dropping retardant, just to show they are doing something.

The Government needs to be truthful with people, that is, "We cannot stop that fire." "It is beyond our capacity - our planning - our capability."

People in Government must be educated in procedures and understand their roles.

The "rubber meets the road at the local level."

We need a grass roots uprising to solve the problem.

Expand ICS to other agencies--include the sheriff, medical, other agencies on the incident.

There is a reluctance on the part of legislators to get tough. Can the Government take the lead, or must they wait for a disaster to generate the grass roots uprising?

What level of Government takes the lead? It will not be on the local level until a disaster occurs. National level needs to educate the Nation on disaster potential. Smokey should get involved for the long-haul resolution. The National program is only as strong as the local program. We also need the local quick fix. There is a need for public education in rural/urban interface areas to teach fire safety.

We need a "Fire Safe" program like conservation education program.

Need a "60 Minutes" on fire safety (lack of).

"They" are going to build, develop, and sell as much development and "they" can. "They" don't say a word to the purchaser about the risk and hazard--the bottom line is the buck.

My (resident) expectation from the Fire Department is not what I'm going to get. What you want me to do as a resident may not be realistic--you want me to clear 100 feet--I may now own 100 feet!

We have the technology. It is fragmented by layers of Government agencies.

Have the Fire departments critically looked at themselves lately? Are there things I can do? Are they always passing the total buck on to the residents and Government?

FIRE AGENCIES

We are starting to do more disaster drills that involve everyone.

Protection of lives, property, resources.

Pre-incident planning.

We are asked to be prepared outside of our normal fire season to meet needs elsewhere as well as interagency local needs.

Coordinated training programs--integrated purchasing, grant program, surplus program (State and Federal).

Use of public and industry liaison to use their resources.

Safety for firefighters--proper equipment for both structure and wildland fires.

Attention to laws and statutes.

Ability to provide an initial attack force.

RESOURCE MANAGERS

Get public involved beforehand.

Loss of winter range, trapping areas, wood, fiber production, timber.

Know and understand the long- and short-term value of resource.

Use of prescribed fire to enhance resources and lower hazard.

Do your political homework

Protection of watersheds, fisheries, and air quality.

A need for integrated planning and coordination between managers.

Use industries resources.

We usurp some of our program flexibility by tying into long-term goals and fail to respond to immediate needs.

VISITORS

We are all visitors.

GENERAL ISSUES AT LARGE

We have not yet faced what we are willing to risk or give up on some tough issues: property versus resource values.

Today, if you make a mistake, the public will eat your lunch.

I want a quick, fast answer and it isn't there. There is more work to be done.

Anticipated taking back more "tools"--some "how to's" not "shoulds".

We don't have it clearly cut and dried as to who's responsible for what.

The issues are too general, not specific--wanted to see methods discussed.

There is a frustration on how to reach the public with the message you have to give.

We (business) market a product and target the market. Maybe there are ways to meet this need such as community outreach programs (churches, schools, clubs) by your department. Go right to the source of the problem with your message.

Turf--structure versus wildland fire--this is a bullet that has not been bit.

Self-help--people have to get the knowledge--how do we get there?

We've got some information that has not been heard. "Fire services" have to start looking outward, not inward!

COLLECTIVE GROUP EXPERIENCE

Federal Forestry - State and Private

Federal Forestry - Fire, Washington, DC, Minnesota, Montana, Washington

Information Fire

Homeowner in fire environment

State Forestry - Fire (Washington, Wisconsin, Oregon)

Northwest Territory, Canada

Business person

Rancher - NE Wyoming

County Commissioner

County Fire Department (Washington, Oregon)

National Forest Supervisor (California)

State Fire Marshal (Oregon)

Fire Chief (Kananaskis, Alberta, Canada)

Forest Fire Management Officer

Logger/Engineer

SESSION 5

Bruce Coulter, Moderator
Colorado Forest Service
Fort Collins, Colorado

PLANNING FOR THE FUTURE:

HOW CAN WE BETTER DEAL WITH TODAY'S AND TOMORROW'S COMPLEXITIES?

M. Rupert Cutler, Ph.D.

ABSTRACT: Human population growth is the root cause of the escalation in the number of wildfires in rural residential areas. Adoption of growth management strategies such as land use controls, land acquisition, the timing and location of public facility improvements, and the use of tax and fee systems can be used to concentrate human settlements. In the long run, stabilization of the national population through changes in federal laws, including an immigration ceiling, will make the problem easier to solve.

INTRODUCTION

I feel like I've returned to the scene of the crime!

Session moderator Bruce Coulter noted that, a decade ago, I was the Assistant Secretary of Agriculture for Conservation, Research and Education, President Carter's appointee to provide policy direction to the Forest Service. On July 16, 1977, to be precise, I was standing on the Missoula airstrip, being briefed by Regional Forester Bob Torheim on Forest Service wildfire research and management programs.

"We're ready for anything," says Bob.

"Then what are you going to do about that fire in the canyon behind you?" says I.

At that point, half of those briefing me rushed off to assemble a team to fight the Pattee Canyon fire, in the mixed Douglas-fir-single family home forest type which surrounds this and so many other cities in the West.

The Pattee Canyon fire consumed six homes worth $330,000 and 1,200 acres of timber and brush. Suppression costs totalled over $300,000. And there I was, possibly keeping some of the fire staff here from their appointed rounds.

I'd hate to think that fire was staged for my benefit. The Forest Service does go to impressive lengths to impress new assistant secretaries with its expertise.

During that period, when I was in the Office of the Secretary, I used to reassure my Forest Serice friends that I, too, began my career at a low federal grade level, in the field--that I knew what a Pulaski tool was and how to throw mineral soil on a fire with a lady shovel. In 1952 I was a smokechaser and lookout on the Sullivan Lake district of what was then called the Kaniksu forest in northeastern Washington and northern Idaho.

I have choked on smoke, and spent nights on the ground after putting out fires, trying to keep warm by revolving the body near the last still-burning log. I have great respect for firefighters.

We lived in northern Arizona for a while and spent our weekends on the national forests in that part of the region. From these and many other encounters since, I know the Interior West pretty well for a Midwesterner turned Easterner. To my way of thinking, there's no finer country.

But the character of the Interior West is changing rapidly, isn't it? Changing because its human population density is growing--a characteristic it shares with the rest of the country, except that the population is growing faster than average here.

THE U.S. POPULATION GROWTH RATE

We may not be living in a Third World country with a fertility rate of over 4 as in Kenya, but the theoretical doubling time for the U.S. population, at the rate at which we are growing is only 55 years.

As a matter of fact, it already has doubled in my lifetime of 54 years. The population of the United States--123 million when I was born in 1933--is 243 million today. It seems to be headed for the 300-million mark soon after the turn of the century . . . and 400 million people in the U.S. within the next century is within the realm of the possible, if not the desirable.

To take just one Interior West state as an example of what's happening--and may happen--regionally: The population of Colorado has more than tripled since I was born and more than doubled since I was calling in lightning strikes from the Little Snowy Top lookout tower. And we "ain't seen nuthin' yet": Department of Commerce projections show Colorado growing from 3-½ million today to 5-½ million within 40 years, or two generations.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

M. Rupert Cutler is Executive Director, Population-Environment Balance, Inc., Washington, DC.

Denver's population is four times what it was when I arrived on the scene, in the depths of the Great Depression. I'll bet the same could be said for most the cities each of you represent.

Did you know that the United States has the highest population growth rate in the industrialized world? That all but five states gained population in the last five years, with the Interior West states growing at a 5-to-17 percent rate over that period? That this growth has been concentrated in the suburban rings around our cities?

Perhaps you did know that it's in our western cities' suburbs where population growth has been the greatest. After all, one costly result of population growth-driven suburban sprawl--"the escalating problem of wildfires in wildland residential areas throughout the west"--is the reason we're here today.

But do you know the sources of those new residents and the consequent expansion of our urbanized areas, which is giving you fits because of the escalating wildfire problem?

Did you know that there were over 3.7 million births in the U.S. last year, as many as during the Baby Boom years? That one-half million of them were to teen-aged mothers? That, of the roughly two million immigrants who entered the U.S. to stay last year, about three-quarters entered illegally?

And were you aware that the "amnesty" provisions of the Immigration Reform Act of 1986 invite millions of illegal aliens to stay and to bring their families? When they are implemented, the annual flow of legal immigrants will top the one-million mark, unless a firm, overall immigration ceiling at the lower level is adopted soon.

I may have surprised some of you with my emphasis so far on population growth in this "planning for the future" message. You know I've spent most of my life fighting for wildlife and wilderness protection. But I have concluded--and I hope that, when I'm finished this morning, you'll agree--that we can make changes in buildings, landscapes, community design, and management of vegetation until we're blue in the face and we won't have addressed the root cause of residential-area wildfires, only their symptons, important as they are.

Their root cause is population growth.

THE SHORT ANSWER

Now here's my short answer to the specific question your program chairman posed to me, "How can we better deal with today's and tomorrow's complexitities?":

1. Use integrated federal-state-local land use planning at the county or multi-county level to encourage

(a) clustered residential development and

(b) preservation of open space.

Use zoning, growth boundaries, transferrable development rights, purchase of easements, or outright land acquistion to accomplish this.

2. Elect politicians with brains and guts enough to actively support state and federal laws which encourage sex education, easy availability of contraceptives and abortion services; discourage large families; prohibit government subsidy of urban sprawl; prohibit the hiring of illegal aliens; and limit immigration into this country.

LOCAL PLANNING

Let me give you local planners some specific suggestions:

Last year Population-Environment Balance conducted a nationwide inventory to determine where sophisticated techniques of local governance are being used to limit growth and which techniques are being used successfully. The results of our survey are contained between the covers of this booklet entitled" Community Responses of Population Growth and Environmental Stress."

The booklet sells for $5.00. I've brought a supply with me to give you on a first-come, first-served basis.

Here's what we found out. It relates directly to your interest in protecting people and homes from wildfire.

With the support of the David and Lucile Packard Foundation, and under the supervision of Robert J. Gray, who directed the well-publicized National Agricultural Lands Survey for the Carter Administration, BALANCE staff members called local planners in 1,500 cities and counties, to quiz them on the characteristics of their local land use planning programs.

Applying certain quality criteria to these data, we concluded that we had found 280 cities and counties with true growth management programs worthy of inclusion in our computerized national data base of local growth management strategies. Each community's mix of techniques is different.

The BALANCE survey grouped the 25 different local growth management techniques we discovered into four major categories:

1. Land use controls. Of the 280 programs covered by the inventory, all but two include some form of land use control such as zoning, the grandfather of all growth management devices.

2. Land acquisition. Absolute ownership of a parcel is one technique. Others involve acquisition of partial interests in real estate, the payment of compensation to property owners whose property has been "down-zoned" to such a degree

that its value is markedly impaired, and the imposition of restrictive covenants on land which has passed through community ownership.

3. Public facility improvements. Among the new techniques working their way into the planning ordinances of many communities are those which schedule the timing and/or location of public facility improvement as a way of regulating growth. Because most development depends in one way or another on public expenditures, long-range planning for sewer, water and highway construction can be an effective way to influence the rate, location and timing of growth.

4. Tax and fee systems. The use of taxes and fees is a relatively new development in growth management. They may take on added significance in the future as economic pressures force communities to locate new revenue sources to meet their growing budgetary demands, while curtailing the growth which adds inevitably to their economic burden.

The type of program selected and the specific techniques used vary from one region of the United States to another. Let me give you an idea of how this cuts:

Land use control is the principal growth management tool in the Northeast, with land acquisition and public facilities improvements also playing significant roles. Communities there also are adopting fees imposed on developers and other devices to shift the cost burden of new growth away from the public sector.

In the South, environmental controls are prominent. Concern for floodplain and ground water protection is obvious. Local programs in the North Central region emphasize agricultural land protection, environmental controls, and the timing of public facilities such as water and sewer.

The West yielded an abundance of growth management programs, including many innovative techniques that have little representation in other parts of the country. Land use controls are the major growth management technique here, together with the timing of public facilities. The growth boundary or urban limit is becoming an important element in the West.

Wouldn't growth boundaries help protect people and homes from wildfire?

The growth boundary establishes a line separating urban and rural areas. It is designed to protect open space and agricultural land. It defines the limit within which the full range of urban services will be provided. The purpose is to promote compact urban development within and adjacent to existing urban areas, insure efficient use of land resources, and facilitate least-cost provision of public services.

I was particularly interested to note that many communities have set specific goals to limit growth. Attempts to manage growth by placing upper limits on population, residential development, or commercial/industrial development appeared in 128 of the 280 documented programs. Twenty-four of the programs we identified include an overall limit on population. Sixty-six communities reported that limiting residential development was an objective of their program. Thirty-eight programs include a cap on commercial or industrial development.

And well they might decide to limit residential development. At least three studies I'm aware of--conducted by the President's Council on Environmental Quality, the American Farmland Trust, and now by Population-Environment Balance (in two booming counties in Maryland)--show that new subdivisions never pay for the public services they require.

The high cost of providing new residential developments with roads, water supply and sewage-treatment systems, schools, and school bus service always is subsidized by the pre-existing residents of a community. This subsidy escalates substantially when the new development occurs on large lots. When wells and septic systems fail, the cost of connecting these homes to public sewer and water--to end the groundwater pollution and public health problems so created--is extremely high.

MYTHS OF GROWTH

Incidentally, BALANCE recently published a one-page fact sheet called "The Myths of Growth" which might be of use to those of you interested in enlightening your constituencies regarding the downside of continuing residential growth in your communities. These are the myths we attempted to dispel:

Myth No. 1: "New development increases a community's tax base, spreads the tax burden among more people, and lowers everyone's individual tax rates." Fact: New residential development must be subsidized through higher taxes paid by all. The costs of new schools, roads, police and fire protection, water and sewer lines and other services will far exceed the tax income generated by the new housing development.

Myth No. 2: "Growth management programs cause land prices to escalate, making private homes more expensive." Fact: Most growth management programs streamline the permitting process by locating all agencies with which a developer must deal in one location. The review process is expedited. A well-devised growth management program stabilizes land prices because it eliminates the element of speculation, the driving force behind rising land prices in most urban regions.

Myth No. 3: "Growth management will increase the cost of public service such as water, sewers, and highways." Fact: Without a growth management program, sprawl, strip development, and leap-frog development occur, creating the need for enormously expensive improvements in public services. Growth management programs channel growth into those areas which have sufficient public service available, making them extremely cost-effective.

Myth No. 4: "Growth management programs are elitist because they exclude low-income families." Fact: Modern growth management programs make affordable housing an integral part of the community plan.

Finally, Myth No. 5: "If every community in the United States adopted a growth management plan, eventually there would be a housing shortage." A community which reaches its growth limit under a growth management plan would be no different than a desirable residential subdivision which is completely built out or an apartment complex in which all of the units have been rented. A person who wants to live in one of those locations must wait until a house or an apartment becomes available. This scenario is repeated every day across the country without oppressive results.

GROWTH MANAGEMENT CLEARINGHOUSE

Just to whet your appetite for more information from our Growth Management Clearinghouse--and you can call BALANCE's General Counsel, Gene Ruane, who once was a county planning commissioner himself, for the details--here's the complete list of 25 growth management techniques we discovered. They have been tried and tested and are available for your use in your communities to reduce the wildfire hazard, save working forests and keep taxes down.

Under "Land use controls" we found, in the order of their frequency: subdivision regulations; convential zoning; floodplain zoning; planned unit development; cluster zoning; critical area zoning; conditional zoning; non-exclusive agricultural zoning; bonus/incentive zoning; performance zoning; exclusive agricultural zoning; and building permit limitations.

Under the heading "land acquisition" we found: fee simple acquisition; conservation easements; advance site acquisitions; restrictive agreements; purchase of development rights; transfer of development rights; and land banking.

"Public facilities improvements" include capital improvement programming, development timing, and annexation.

"Tax and fee systems" mean that some communities are using development fees, urban/rural service area assessments, and/or land gain taxation to control their growth.

NATIONAL PLANNING: THE CONTEXT

The second part of my answer to the chairman's question, "How can we better deal with today's and tomorrow's complexities?" was: Stop U.S. population growth. That's the only way to take the pressure off your communities in the long run. That's not my idea; it was expressed by the Commission of Population Growth and the American Future, chaired by John D. Rockefeller 3rd, 15 years ago. The commission's lengthy final report concluded:

"The stabilization of our population would contribute significantly to the Nation's ability to solve its problems."

If we can't slow our population growth, this is what's in store for us: Our present demographic trajectory, with no population policy changes, will put our nation's population at between 270 and 300 million in the year 2000. That's between 30 and 60 million more people, most of them living in our already crowded existing metropolitan areas, all of them needing food, shelter, energy, and jobs. Our population could reach 400 million within the next century.

Let me appeal now to both halves of your brain, by showing a few slides prepared by the staff of American Demographics magazine:

1. U.S. Resident Population, 1980-2000. We think 265 million by the year 2000 is on the low side, and that 280 million will be closer to the mark, unless an immigration ceiling is adopted soon.

2. U.S. Population, 1980-2050. You can ignore the yellow line; zero immigration is not likely. Again, without a firm annual limit on immigration, we're looking at a U.S. population of over 350 million--100 million more than today--by the middle of the next century.

3. U.S. Household Growth. The rate of growth in households is much greater than the rate of population growth, meaning increased numbers of houses --accelerated urban sprawl. Just what you wanted to hear!

4. Population Change, 1980-1985. To quote our own BALANCE-data No. 22: "From 1980 to 1985 the population of the United States grew by 12.2 million people, an increase of 5.4 percent over 5 years. Although the growth is concentrated in the Southwest and Southeast, over the last five years, population has increased in every region of the U.S."

5. Projected Population Change, 1985-1995. The West will grow by 13 percent.

6. Ten Fastest Growing Metropolitan Areas, 1983-2005. Santa Fe is at the top followed by three metro areas in Florida, and then two in Texas.

7. Finally, Immigration to the U.S., 1950-1985. In 1985, says this graphic, 46 percent came from Asia, 37 percent from Latin America, and 11 percent from Europe. But at the April 1987 meeting of the Population Association of America, I learne that the most recent tabulation shows that half of recent immigrants are from Latin America, 29 percent were from Asia, and 21 percent were from Europe and Africa. Practically all of them gravitate to our big cities. One-third of the growth of U.S. metro areas is due to immigration.

NATIONAL PLANNING: THE AGENDA

Think ahead with me to the future, and ask yourself: Will we as a nation adopt a sound population policy, calling for a stabilized population, to minimize costly congestion, keep resource demands in balance with supplies, and alleviate the boomtown, urban-sprawl pressures on our smaller cities?

Here is what the adoption of such a policy would mean:

1. No government incentives to have large families, including the unlimited income tax personal exemptions for dependents. That baby bonus would have to go.

2. No government subsidies for construction of new roads, airports, hospitals, sewer and water lines and other infrastructure outside already urbanized areas--subsidies which encourage urban sprawl onto farm and forest land, wetlands and flood plains.

3. Universal, effective public school sex education and population education from the earliest grades. Easy access by teenagers and others to birth control information, materials and services including affordable abortion services.

4. Real control of our international borders, to limit the number of immigrants coming in to the number of emigrants permanently leaving the country.

That, you'll agree, is a list of very difficult political objectives. But what is the alternative? Only continued growth.

CONCLUSION

Now that you know the facts--that hundreds of communities all over the country are successfully managing their growth; that our high fertility and immigration rates threaten to undo everything we put in place to direct growth and minimize land use conflicts--won't you help us accomplish two means of preparing for the future? They are:

1. Encourage local citizen volunteers to learn about and participate in local governance, to create an active constituency for good planning and local growth management in your communities; and

2. Encourage the associations you belong to to join with Population-Environment Balance in the campaign to win passage in the U.S. Congress of legislation to win a national policy of population stabilization, including the adoption of an annual immigration ceiling, and let your own representatives in Congress know you feel this way. The bills now pending before the Congress to take the necessary first steps are H.R. 2212 in the House and S. 1171 in the Senate.

On the basis of this two-pronged approach, progress can be made toward holding our population within the carrying capacities of both our communities and our nation. In the process, we can minimize the growth in wildfire risk at the urbanizing fringes of our rural communities.

Local growth management and national population stabilization, we must hope, are mature concepts ready for adoption. As Victor Hugo wrote,

> "Greater than the tread of mighty armies is an idea whose time has come."

Thank you.

CREATIVE TECHNIQUES FOR FIRE HAZARD PLANNING

Bruce A. Bugbee

ABSTRACT: Among today's planning tools, there exists attractive, cost-effective techniques which can be voluntarily implemented. When these techniques are employed by knowledgeable landowners, land use planners, and/or fire ecologists, risk of loss by fire can be reduced substantially. Both the landowner and the public benefit from these creative techniques for fire hazard planning.

INTRODUCTION

As our population, affluence, and mobility have increased, non-urban land has felt a new burden. Second home development, utility and transportation corridors, recreational developments, and recreational users have spread into lands with valuable wildlife habitat, open space, and agricultural production. Such land can be intolerant to much development, and substantial hazards exist to people who use those areas. Development in floodplains, on unstable slopes, and in frequent fire zones are examples. In dealing with fire hazard, there are two separate issues to resolve: 1) How to avoid building in rural areas which have high fire potential; and 2) if building is done, how to build in ways which reduce loss by fire.

In order to succeed at these tasks, some assumptions are necessary. These are:

1) Fire ecologists can and will identify areas of high fire risk.

2) Once such areas are identified, effective management techniques can be developed. These include forest and range harvest, prescribed burning, residential construction design, site preparation and maintenance, road design, emergency equipment access, escape routes, wildlife management, and infestation of insects and disease.

3) Most rural areas have few, if any, regulations regarding fire prevention. Regulatory techniques such as subdivision and zoning tend to do only part of the job. They often address how to build but not the environmental impact of such building, nor the risks associated with it.

4) Implementation of appropriate techniques requires the cooperation of a variety of people. Among these are fire ecologists, fire fighters, land use planners, public land managers, and private landowners.

To address fire hazard, a example can be made of other land use planning problems in which the objective is to limit or prohibit residential development without regulation and to do it in ways which protect wildlife habitat, wetlands, open space, recreation areas, and/or municipal water supplies. The solutions to those problems are relatively simple: either buy the property or acquire limited interests in the property sufficient to accomplish the objective. Cooperation on the landowner's part is voluntary.

Protecting all high fire hazard zones in rural areas is an ambitious and intimidating task. Should all privately-owned rural lands be bought and owned by the public? Probably not. However, let us assume that something between 1% and 10% of the privately-owned rural landscape is the area of most critical fire concern. These would be areas of the urban-rural interface, of high recreation use, as we as areas of rapid accumulation of volati fuels. For these areas, land use plannin techniques used with the full cooperatio of the landowner can be an excellent sol tion to high fire hazard problems.

A brief review our our land ownership system is necessary to understand how su voluntary land conservation devices work Our system of land ownership operates on two levels. One is abstract, and the other is tangible.

Our legal system recognizes an individual's right to own land. Ownership includes possession of whatever is over, under, and on a given piece of property. Typical rights of ownership include

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Bruce A. Bugbee is a Land Use and Conservation Planning Consultant whose office is located in Missoula, Montana.

minerals, access, water, timber, agricultural use, industrial use, and residential use. The property's size, shape, location, scarcity, relation to surrounding land, soil, vegetation, slope, water availability, wildlife, visibility to others, and history of use are tangible aspects of land ownership. These qualities shape legal rights of use. The right of ownership also carries with it the right to convey property or property rights to others. Conveyance may be made by gift, sale, or will.

Our legal system also provides for the well-being of the community as well as the individual. Our society believes the exercise of individual rights ought not harm other persons' rights. To protect against such harm, our society has provided us with what our Constitution refers to as "police power authority." Police power authority is the base from which grows regulation of subdivision, zoning, and building codes.

Historically, the public has decided there are certain lands which should be publicly-owned, such as national forests, parks, game refuges, and wilderness. The public has also decided that air, water, and wildlife belong to everyone. Some have suggested the public should have an interest in how individual landowners make decisions relating to fire hazard reduction. However, that which the public owns and that which the public values are not always the same. Sufficient motivation is essential for property ownership to change. Voluntary land conservation techniques are built upon motives and incentives which are beneficial to both the landowner and the public.

All voluntary techniques require the free consent of both parties to the transaction. Should the parties fail to reach agreement, no transaction takes place. Therefore, substantial motivation of the parties is a key ingredient to a successful transaction. Substantial motivation can be protection of the landowner's traditional life style from irresponsible public use, land trades which make management more efficient, or some financial compensation.

The techniques described in the following text have been developed primarily for preservation of wildlife habitat and open space. They are usually directed toward maintaining historic, agricultural land uses and preventing conversion of rural land to urban uses. Consequently, some of these strategies can be applied to meet fire hazard planning objectives.

FEE AND LESS-THAN-FEE CONVEYANCES

Voluntary techniques for land conservation generally deal with two types of property interests, fee ownership and less-than-fee ownership.

Fee Conveyances

There are some circumstances which require acquisition of outright ownership of the full "fee" title for conservation of the property. Generally, fee ownership of a particular property is necessary when public values, including fire hazard reduction, are complex and require substantial management control.

Areas considered for fee ownership include not only habitats for rare and endangered species, but intensive public use areas, such as campgrounds and picnic areas, sites for public buildings, and historic sites which require specialized management to preserve the historic character. Also included are private inholdings within public lands committed to special mangement and within which privates uses of any kind would be incompatible. Fire hazard areas suitable for public ownership might include high hazard areas requiring regular and substantial fuels management, as well as private lands surrounded by public lands with substantial fire hazard risk.

Less-than-Fee Conveyances

Conservation Easements--The device which has the greatest potential for fire hazard management is partial public ownership, or a "less-than-fee" conveyance. A conservation easement is an example of a less-than-fee device. Most of the rights of ownership remain with the landowner while limited rights, such as the right to develop property, are conveyed to a public or non-profit conservation organization. The property remains on the tax rolls and under management by the private landowner. Public access may or may not be part of such an agreement. Emergency vehicle and fire management access can be part of such an agreement.

Conservation easements reflect common goals shared by both parties to the agreement. Each conservation easement is different as to which rights will be conveyed because each easement reflects the significant conservation values found on the particular property for which it was written. In Montana, Conservation easements are recognized by State law (76-6-101, et seq. MCA). Federal regulations provide that donations of perpetual conservation easements can qualify grantors for certain tax advantages.

Reg. Sec. 1.170A-14(d)(4)(i)

(4) Preservation of open space--(i) In general. The donation of a qualified real property interest to preserve open space (including farmland and forest land) will meet the conservation purposes test of this section if such preservation is--

- (A) Pursuant to a clearly delineated federal, state, or local governmental conservation policy and will yield a significant public benefit, or,
- (B) For the scenic enjoyment of the general public and will yield a significant public benefit.

Conservation easements are best used to protect significant public values on private land when public values have coexisted with historic and present private land use, and the owner wants to retain the land. In these situations, maintenance of conservation values may be possible by simply continuing the historic range of compatible uses of the land. Fire hazard reduction and fuels management can be specific objectives. No public access is necessary in that situation. Conservation easements prohibit the conversion of the property to new, incompatible uses, such as subdivision development on elk winter range or high fire risk areas.

Other types of less-than fee conveyances include:

Public Access Easements--A public access easement conveys the right of public access. That access may be specifically designated, such as a road access, fire control access, fire break roads, trail access, access for parking, or boat access. The access agreement may be for set period of time (term agreement) or i perpetuity (perpetual easement.)

Term Agreements--In some circumstances, either the landowner or the public agenc may not be prepared to enter into a perpetual conservation easement or public access easement. Also, certain shared responsibilities are oriented to short term management concerns rather than to permanent commitments of land use. For example, a short-term agreement may be appropriate for an experimental prescrib burning or fuel reduction program.

A term agreement can be set up for a certain number of years. This term can whatever the landowner and the agency agree to. However, generally no tax incentives are available. Term agreements may be helpful in situations when larger undeveloped properties are adjacent to developing areas and the landowner has n immediate plans for development.

Term agreements also can be used to allo limited public access to a stream or par Specific areas can be designated for cam fires and high fuel hazard areas can be avoided. Time of year of access can als be controlled. Local, State, and Federa agencies can provide support for seasona enforcement. If the public is not respo sible in its use, the agreement can be terminated by the landowners.

CHARACTERISTICS OF FEE AND LESS-THAN FEE EASEMENTS

Less-than-Fee Ownership	Fee Ownership
Partial legal interest: only those rights necessary to protect conservation values	Full-right title and interest
Lower cost acquisition	Higher cost acquisition
Lower management costs: landowner responsibility	Higher management costs: public responsibility
Widespread application	Limited application due to economic and political constraints
Land stays on tax rolls	Land removed from tax rolls
Perpetuates historic (mostly agricultural/silvicultural land uses/lifestyles	Can change historic (agricultural/silvicultural) land use to intensive public uses
Encourages sense of individual responsibility to community	Encourages dependence on government for solutions

ETHODS OF COMPENSATION

onservation Bonds

tate and local government have the authority to initiate bonds to raise money or conservation land acquisitions. These onds can be created only by majority ublic vote. In 1981, the City of issoula received voter approval for a 500,000 bond. The money was designated or acquisition of downtown riverfront and cenic open space on nearby Mount Jumbo nd Mount Sentinel. Mount Sentinel has ad major fires almost every year in ecent history. A conservation easement urchased with conservation bond dollars as prevented development forever. Negotiations for acquisition of appropriate arcels were handled by existing City taff and assisted by a citizen review oard.

ooperative Management Districts

ooperative Management Districts (CMDs) efine large areas of conservation, open pace, and recreation needs and secure roperty rights to provide for those eeds. Local, state, and federal governments can cooperate to designate CMDs for arge regions. With proper planning, fire azard reduction and development conflict voidance can be design components of hese sysems. The Greater Yellowstone cosystem is an area currently under consideration for a Cooperative Management istric, With CMDs, Park dedications from ubdivision development could be accepted y local government only in areas desigated for open space and recreation. Subivision developers could be encouraged to urchase pre-designated areas to satisfy he park and open space dedication reuirements of their subdivisions. In reas of compatible historic use by rivate landowners, open space could coninue to be used for compatible agriculural or forestry purposes. Private wnership could be maintained subject to onservation easements.

xchanges

xchanges can be used to consolidate ublic land holdings and prevent developent in high fire risk areas. The obective of a land exchange is to find two arcels of land owned by parties who have qually strong desires to possess the land f the other. For the private landowner, ompensation occurs by means of the land e acquires.

here is no guarantee of success when an xchange is initiated. There is a risk hat, as the process develops, either of he parties will become disinterested or conclude there is inequity in the exchange and terminate the process. Exchanges can take a substantial amount of time and can involve a variety of financial and legal advisors.

When government lands are involved in an exchange, the public's interest in the trade lands must be protected. Public support is required for the exchange to proceed. Acquisition of the private lands must also be in the public's interest. Environmental assessments, appraisals of land values, and public hearings are prerequisites for such exchanges to take place. Therefore, land exchanges should be considered only when the private lands have sufficiently high priority to warrant the expenditure of public resources without guarantee of success.

Several land exchanges have occurred in Missoula County in its recent history. These exchanges have been successful in acquiring high priority private lands and therefore preventing development in high fire risk areas. One example of such an exchange occurred in the Rattlesnake National Recreation Area and Wilderness between the Forest Service and Montana Power Company. 21,000 acres of Montana Power Company land existed as a checkerboard inholding of prime subdivision land beginning on the edge of existing suburban development. Subdivision development in this pattern could have been disasterous for future residents of the area in the event of fire. Both wild fires and prescribed burns have occurred in this area since the exchange was completed.

Design Solutions

A design solution is structured to parallel a comprehensive plan. A careful resource and development analysis is prepared for the landowner's property. This analysis results in clear definition of where high priority public values are located, how they can be preserved, as well as where and how the landowner could pursue other land use options (such as limited development) in a manner compatible with the public values. The analysis can include components such as emergency equipment access, controlled areas for open fires, homesite location controls, and fuel reduction programs.

If areas of the property are found which are suitable for intensive or limited development, and such development is compatible with the maintenance of conservation and fire planning concerns, the design solution forms the basis for the local government and the landowner to enter into an agreement. A conservation easement or land conveyance is designed and prepared for implementation at the time the development decision is made. The ability to develop land in a limited area, combined with the income tax deduction made available by the easement, may maximize return to the landowner while minimizing the area needed for development. The use of tax incentives requires careful coordination with the landowner's professional legal and tax advisers.

CASE STUDY:

LESS-THAN-FEE CONVEYANCE -- CONSERVATION EASEMENT

Subject Property: Western Montana's Blackfoot River Conservation Easement Program

Situation: In the early 1970s, water-related recreation use on the Blackfoot River was increasing dramatically. With increase in use came increase in conflicts between private landowners and public recreationists. Littering, trespass, vandalism, and fires caused deteriorating relationships between recreationists and landowners.

Parties Involved: Several private landowners, recreation user group representatives, Lubrecht Forest, Montana Department of Fish, Wildlife and Parks, Missoula County, and The Nature Conservancy.

Choices:	Consequences:
Do Nothing	Landowner-recreationist conflicts would continue to increase; discouraged landowners would sell out to recreation subdivision interests; river access would become even more restricted, and high recreation qualities were likely to be lost
Zoning/Subdivision Regulations	Highly unpopular with landowners; if successful would allow changes from larger farm and ranch tracts to 20-40 acre parcels with occasional sales which could reduce lot size further
Establish Wild and Scenic River	Locally unpopular; high public expense of buy-out; long implementation period allowing conversion of land in the interim; reduce private property tax bas
Reach Agreement among Landowners to Maintain Traditional Land Uses and Allow Responsible Public Use	Limit conversion of traditional land uses; allow responsible public use; some public expenditure to assist with river corridor management; landowners retain control of their property

Decision: Establish a voluntary conservation easement program and negotiate a term public access agreement

Results: Approximately 5,000-6,000 acres under permanent conservation easements protecting several miles of Blackfoot River frontage in traditional agricultural and timber land uses. Public access agreements negotiated separately for approximately 26 miles of Blackfoot River; almost total elimination of man-caused wild fires.

SUMMARY

In land conservation, the most common form of compensation is personal satisfaction of the landowner. Most rural landowners choose their lifestyles because they enjoy open spaces, wildlife, recreation, and/or working with the land. They would also like to do this safely. Local government is in a unique position to support the continuation of such values and provide safety. Such support, in whatever form it takes, can be compensation. Fire planning officials can work with State and Federal agency conservation lands acquisition programs to integrate local conservation objectives with fire hazard reduction.

There are a number of voluntary strategies which have accomplished major conservation goals which aid in fire hazard reduction. Many organizations and individuals are able and willing to help. Federal and State governments have been actively acquiring or trading properties for public purposes for a long time. National nonprofit conservation organizations such as The Nature Conservancy and the Trust for Public Land have been extremely effective.

In the 1985 issue of Land Trust Exchange, a journal reporting land trust activities nationally, survey results were presented on conservation easement use in the United States. As of that year, some 1,780,000 acres of land had been protected through the use of conservation easements. Conservation easements are found in nearly every state. There are some 500 organizations and government agencies which hold conservation easements in the U.S. 146 of these are county governments.

On a national scale, the prospect of land acquisition for fire hazard reduction is challenging if not intimidating. Those interested in protecting valuable areas of wildlife habitat, open space, and recreational resources have faced similarly intimidating work. However, during the last two decades, professionals in those areas have met that challenge with surprising success. Their successes have also meant, in many instances, prevention of future conflicts between development and wildfire.

The idea that fire is a part of the ecosystem's health is not surprising to those who work with environmental concerns. The idea that planning should purposefully incorporate strategies for fire hazard risk reduction is new. Federal laws which authorize purchases of land and facilitate charitable contribution treatment for donations of land in conservation easements can easily be interpreted to include public policies specifically designed for fire hazard reduction. In this instance, being creative means borrowing effective land conservation technology and making it work to reduce fire hazard, too.

REFERENCES

Bugbee, Bruce A. 1986. Voluntary Techniques for Conservation of Open Space. Missoula: Bugbee & Associates.

Goetz, Hank. 1983. The Blackfoot River: A Landowner's Approach to Management. Western Wildlands. Fall: 20-23.

Whyte, William H. 1968. The Last Landscape. New York: Doubleday & Co. 376 p.

COUNTY LAND USE PLANNING, HOW CAN PLANNERS HELP THE FIRE SERVICES IN PROTECTING HOMES FROM WILDFIRE

Guy R. Groves

ABSTRACT: In Jefferson County we have established a procedure that is being implemented now that addresses the issue of wildfire at the development process. As a part of the development process we require that, where a hazard exists, a forest management plan be implemented prior to the conveyance of property ownership or just prior to building. A building permit will not be issued until a forest management plan is completed. Implementing this procedure has resulted in better relationships between Jefferson county, the Colorado State Forest Service, and local fire protection districts.

INTRODUCTION

The basic objective for local government is: "to protect the health, safety, and welfare of its citizens." It is this objective that gives rise to all the functions / services provided and managed by local government, such as land use planning. Planning responsibilities include: develop master plans, develop zoning ordinances, reviewing development proposals, and issuing building permits. In addition to these "chartered activities", typically required by statute, there are additional activities that exist as "functional" requirements: administration, information dissemination, education, facilitation, and research.

It is obvious that wildfires are a "public health, safety, and welfare" issue, and therefore can be considered as an issue that local government can take an active role in managing. It can be considered within any of the processes performed by a planning department. It is however, one of many issues that must be considered in the development process. Other issues include: transportation; availability of water; sewer, fire, police and other services; wildlife; visual impacts; historic resources; geologic hazards; flood hazards; and other environmental concerns.

The extent to which wildfire is considered depends upon the following: 1) Is wildfire acknowledged as a hazard (issue) at all, or is it ignored? 2) Is there sufficient information and understanding about the problem to include it as a consideration in the development process? 3) Is there a procedure and the appropriate personnel to implement wildfire hazard concerns? 4) Is there political support to manage the problem and what weight does it carry in relation to the other issues that must be addressed?

Wildfire is frequently acknowledged as an issue to be addressed in the planning processes. The exposure this issue has received in the past few years has increased dramatically. Some ten years ago, in Colorado, this issue was officially recognized by the state legislature. At that time there was a land use bill approved that required local governments to identify and manage "areas of state concern", one of which was wildfire hazards. Although the bill may be criticized for not providing good implementation tools or enough authority, it did have some very positive effects. First, it recognized and legitimized many issues that prior to that time were not properly considered in the land use decision process. Second, it provided funds to local governments to identify and develop management strategies for areas of state concern. Since this time there has been a national trend that has recognized wildfires as a growing land use concern. This trend started in areas that had serious wildfire hazard concerns, such as California, and is also exhibited by this and other conferences addressing wildfire hazards.

More recently there has been a greater amount of information and experience with managing wildfire hazard in the development process. There is still a problem with distribution of the information among fire professionals and planners. There is a need for more information sharing and cross training so that planners are more aware of fire protection, and fire protection entities are more aware of the local planning process.

It is probably safe to say that most planning departments don't have professional foresters or a natural resource specialist on staff to help them. This deficiency requires that they obtain resources from outside their organization to help them address wildfire hazards.

More importantly, the issue is not in the public forefront. Many people who move to the intermountain west are unaware of basic issues such as how they get their water (well versus public supply) and how services are provided. They probably have never heard of "geologic hazards" or "wildfire hazards." The greatest obstacle to overcome can be this ignorance among the general public.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Guy R. Groves, Jefferson County Planning Department, 18301 West 10th Avenue, Golden, CO 80401; Guy R. Groves is a land use planner in the Policy Development section of the planning department.

Although there is support and awareness within the professional communities, general public and political unawareness remains. Even where there is an awareness there is often the attitude that "it won't happen to me." Unfortunately, statistically they are right, the odds are (if you're a gambling person) that "it won't happen to me." The corollary, that is only discovered when it happens, is "To those that it happens to, it happens 100 percent."

Culturally there is a dynamic that suppresses the issue of wildfire hazards importance. The more frequently an issue is raised through occurrence and experience the more public attention and political weight it carries. The most frequent top issue in local governments is the condition of local roads because of their high profile. When roads are in bad shape local officials hear about it from the public on a daily basis because: 1) we experience the problem first hand, and 2) we all use our roads with a high degree of frequency, many times daily.

On the other hand, we typically hear about wildfire hazards on the news, and most of us don't experience them. Since they only occur for a short duration over the year, the frequency of exposure to the issue is low.

WILDFIRE HAZARDS & PLANNING

Historic Perspective

The methods used to manage for wildfire hazards in Jefferson County have evolved incrementally over a number of years. With the start of the House Bill 1041 program to identify areas of state interest, Jefferson County seized the opportunity to leverage its capabilities. The county planning department was in the process of developing a geographic information/modeling system to be used for plan development and development review. We applied for and received funds from the state that helped us to continue development of the automated system and collect resource information about the county such as vegetation, surface material, geology, and a host of other issues.

We were starting a "master planning" process for the county of which wildfire would be a criteria used to consider the suitability of a site for various forms of development. At the same time, also as a response to HB 1041, the Colorado State Forest Service started to map wildfire hazards for counties. Jefferson was the first county mapped but the time and resources to code the data into the automated system used for plan development were not available. As an alternative we interpreted from other information: vegetation and slope, using the latest version of the National Fire Danger Rating System - 1978 along with NOAA climate data and local Fire Weather Data available from the U.S. Forest Service to identify hazard levels for the county land use plan.

The bill also required that the county adopt a strategy to manage the areas of state concern. Since we were also in the process of identifying geologic hazards we decided to leverage our efforts by employing the same strategy for both issues. Our management strategy was to develop a Wildfire Hazard Overlay Zone District using the Colorado State Forest Service wildfire maps to identify hazard areas.

We established a Wildfire Hazard Overlay Zone district in the zoning regulations and outlined the process to be used. In prototyping the process we encountered some serious problems. To implement the zone districts we would naturally have to perform county initiated rezoning of all areas identified as a wildfire hazard where we wanted to ensure that mitigation would occur. To perform the rezonings would require that the planning department:

1) Obtain a legal description of each hazard area.
2) Post each area with signs that were easily viewed by the public.
3) Post public notices and descriptions in the local newspaper.
4) Notify all property owners within and adjacent to the areas proposed for overlay zoning.
5) Hold public hearings on the zonings.
6) Draw and adopt a map of those sites that were successfully overlay zoned.

Any entity rezoning property must go through this process. The problems presented with rezoning this many areas of the county in mass presented many difficulties. First there was the cost associated with obtaining legal descriptions for each hazard area. At the time we produced legal descriptions by digitizing from 1:24000 USGS quad. maps, a costly process in 1976 and 1977. Legal descriptions produced by this process were of little to no value given the map scale used and geodetic control. However, it met the legal requirement at the time. Next there was the issue of posting all the sites. Each site would have to be identified on the ground and posted with a standard rezoning sign. In addition, areas not easily visible from a road would also have to be posted along the road to adequately inform the public of the proposed action. Finally there was the problem of notifying all the property owners within and adjacent to the hazards as to the proposed overlay zonings. This was assessed to be a task that the county physically just could not perform, nor afford. The county simply didn't have the capability to perform these tasks within reasonable means. It should be mentioned that with the advent of more sophisticated Geographic Information Systems many of these tasks can now be performed quite reasonably. The problem would continue to be the availability of resources and funds for such a program. The "coup de grace" was the issue of what the county would do over time as the boundaries of the hazard areas change. Due to the dynamic nature of the environment, the process would be continuous as hazard areas changed. If we couldn't reasonably accomplish the first overlay zoning we certainly couldn't maintain any changes in the overlay districts.

As a result the "Wildfire Hazard Overlay Zone" districts were abandoned as a method to manage this issue. Instead we adopted a procedural guide where all rezonings, and platting activities would be referred to the Colorado State Forest Service for review and comment, specifically for wildfire hazards. At first they were handled as comments from a referral agency, since the Colorado State Forest Service doesn't have any regulatory authority it had to rely on the county to implement its recommendations. As time went by the county commissioners' confidence in staff and the Colorado State Forest Service increased and the planning department became more effective at selling its positions regarding wildfire hazards.

Currently it is common practice for the planning department to have wildfire hazard mitigation as written restrictions on subdivisions of land in the development review process.

As a result of the department's effectiveness in obtaining written restrictions regarding wildfire hazards, the development community has been more receptive to utilize the Colorado State Forest Service for forest management of properties prior to their submission of plat proposals. This has allowed us to implement wildfire hazard mitigation and improve overall forest management.

Comprehensive land use plans

Land use plans, master plans, or comprehensive land use plans are product labels used to describe a responsibility of local government to designate acceptable land uses throughout its jurisdiction. Its purpose is to describe a desirable pattern of land use activities that ensure the publics "health, safety, and welfare." To do this, it must consider such things as: current uses, population needs, land capability, and provision of public services such as water, sewer, police, and fire protection.

Within a master plan, the presence of various environmental, demographic, infrastructure, and political conditions determine basic suitability of land parcels for various uses. Again, wildfire is one of many issues in determining the suitability of land for particular uses.

Typically, a master plan results in a map that describes acceptable land uses for particular areas of a community and illustrates the desired pattern of the uses across the community. The master plan map is a synthesis of the policies that determine land use suitability. To include an issue, the features must be mapped and policy must be developed to determine the effect of the feature on a particular forms of development.

The plan development process in Jefferson County is a three tiered structure. We have a Jefferson County General Land Use Plan, special land use plans, and community plans. The three types of plans are used to balance our resources to:
1) cover the entire counties land use plan needs,
2) provide special plans that address specific land uses such as landfills, gravel mining, and communications towers, and 3) provide plans that meet the specific needs of small communities.

The issue of wildfire hazards is incorporated into all three of these plan development efforts. In the General Land Use Plan, policy is incorporated that can be applied throughout the county. In special land use plans, policies are incorporated that address the specific land use. In community plans, the policies address wildfire conditions that are unique to that community. In applying the plans during the rezoning process special land use plans and community plans take precedence over the General Land Use Plan.

The plans give policy that are to be used in the approval or denial of land use changes. Each policy area gives the suitability for land use activities for each issue. A land use pattern map is available that shows a synthesis of the policies and provides guidelines for the future development of the area. In most cases the land use pattern map depicts a range of acceptable land use activities, not single specific land uses. Mapped base data is available to determine what the specific issues and impacts are, and where they are located.

Zoning

Local government has been given the responsibility of "zoning" land. Zoning identifies the basic type and intensity of land use that is acceptable. Types of land use include: agricultural, residential, commercial, office, and industrial. Intensity is a description of the quantity of development or activity, such as the number of residential units per acre, or the number of square feet of commercial per acre along with listings of permitted activities, and some basic "building envelope" constraints such as set backs.

It is possible to manage wildfire hazards through zoning. One approach is to create "overlay zone districts" for wildfire hazard areas. This technique is frequently used to restrict zoning rights where hazards such as flooding or subsidence might occur. The problem with this approach is that most hazards such as floodplains and subsidence are relatively static, they don't change significantly over time, and the areas are well definable. This is not the case with wildfire hazards. Over the course of a few years the bounds of a hazard area can change significantly. The process of maintaining an accurate, up-to-date map, and conducting the process of rezoning the overlay areas would stress most planning departments far beyond their capacities. In addition, the bounds of a wildfire hazard are not as well defined as, say, a floodplain. Legally it is feasible; functionally, it may be unreasonable to actually perform the tasks required to maintain and manage the system as discussed earlier.

In Jefferson County wildfire is considered in the zoning process through application of the appropriate land use plan. At rezoning it is determined if the proposed use is acceptable given all issues, wildfire being one. In many instances a "Planned Development" approach is recommended so that a greater definition of the desired use is made. It is also possible to define the major form of the development without requiring detailed lot or building placement. Although wildfire is considered there are no restrictions or requirements made at rezoning. The result is that the applicant is put on notice that this is an issue that will be addressed at the time of platting.

Development Review

The development review process involves the subdivision of large land parcels into smaller parcels, referred to as platting. The small lots or individual parcels are typically intended to be built on. It is at this step that a land use proposal must show the location of roads, lots, public areas, easements, utilities etc. This is typically where local governments require improvements to roads, dedications for schools and parks, use restrictions, and performance guarantees. The platting or development review process begins when a land owner submits a detailed development plan for a parcel. The local planning authority reviews the proposal, obtains referrals from other entities such as health, transportation, and other departments at the local and state levels. The local planning authority then presents the positive and negative impacts of the proposed use to local decision makers. With this and public comment a final position is negotiated. As a result of the platting process, a detailed commitment as to the minimum form of the development is made between the local urisdiction and the property developer.

It is a frequent practice to place "restrictions" on a plat. That is the local governing entity may require certain site improvements prior to sale of any parcels. The most typical restrictions are usually landscaping and road improvements. A restriction might also require that a developer "mitigate wildfire hazard areas."

The advantage of this is that the developer can be required to develop and implement a forest/range management plan that mitigates the wildfire hazard prior to construction. Depending upon how it is designed and implemented, it also possible to manage the resource for other factors such as visual impact, wildlife impact, ground water, and other concerns associated with any forest/range management plan. This not only mitigates wildfire hazards, but reduces the overall impact of development on the environment and increases property values.

Disadvantages of this system are that it requires additional resources with the proper expertise to review and inspect forest management plans. It requires additional costs to develop properties which are eventually absorbed by the consumer through higher land costs. Resource are managed at one point in time, during the development process. There is no guarantee that the onsumers, such as new home owners, will properly maintain the sites and prevent the hazard from recurring. Finally, it is implementing forest management on relatively small parcels of land. Adjacent parcels might still present hazards since they are not being managed.

n Jefferson County the Colorado State Forest ervice is sent a referral on all cases in the ural areas of the county, where wildfire hazard s a concern. Currently there is an informal agreement between the county and the Colorado tate Forest Service regarding their referral on wildfire hazards; that is, the county has no obligation or contractual agreement to implement their recommendations. However, the department relies on them to comment on the presence of wildfire hazards and their recommended mitigation action. Recommendations from the Colorado State Forest Service have been implemented in the form of written restriction on the plat, when a hazard is present. The typical restriction requires that a forest management plan be completed, inspected by the Colorado State Forest Service and a letter of compliance received by the county before property is sold or building permits issued. The restriction can be stated in two ways that have a subtle but significant difference. First, the restriction can require that the forest management plan be conducted prior to the sale of property or issuance of a building permit. Second, it might require that the forest management plan must be completed prior to issuance of a building permit.

The first option requires that the subdivider of the land perform the necessary forest management prior to conveying ownership of the property. A benefit of this is that the developer must implement a forest management plan that covers the entire property, including all of its lots. The disadvantage is that it cannot account for special management practices to be employed around homes because the building sites are unknown.

The second option only requires that the management plan be completed prior to issuance of a building permit. Land can be conveyed to a new owner and it becomes incumbent upon the new owner to complete a forest management plan prior to issuance of a building permit. The advantage of this is that the management occurs very close to the time of construction, and can incorporate concerns related to siting the structure. The disadvantage is that typically very small parcels are managed at any one time, and the burden is passed from the subdivider to the new owner.

Building Permits

Most planning departments, through the management of zoning, are the first step in acquiring a building permit. Prior to issuance of a building permit an applicant is required to visit the zoning department to ensure that the parcel is legal, the zoning is correct for the proposed building, and that all conditions of the platting process have been met. After meeting these tests the applicant can then get a building permit, typically from the "building department" that reviews construction plans to ensure that the built structure conforms to local building codes.

Although no wildfire management occurs at this time it is a critical inspection phase for Jefferson County. If there were a restriction on the plat, requiring the mitigation of wildfire hazards, then no building permit could be issued until such condition had been met. This process requires that an inspection occur sometime after mitigation has been completed and prior to the sales of properties or application for a building permit.

Information & Education

As a result of providing public services it is necessary that a planning department provide information and education services to the general public, building community, and local politicians. The degree to which this is performed can vary greatly from one community to the next. In any event, the basic task of providing information about the local process, and educating the public and its own employees is essential to implementing any process.

In some cases information and education are becoming primary products for planning departments. There is a trend towards seeking higher degrees of public involvement in development of land use plans, regulations, and land use decisions. Planning departments have the attention of many people. By properly directing this attention it is possible to impress the importance of wildfire hazards on the general public, development community, and local politicians.

The process of education is employed most frequently at the community level. This occurs most extensively in the development of community plans. When a community is organized, one of the first tasks is to review existing policies and identify those policy areas that the community plan should focus on. In the mountain area of Jefferson County, one of those concerns has always been wildfire hazards. Presentations by staff, local experts, and the Colorado State Forest Service serve as educational platforms for the public. In addition, general public meetings (show and tell forums) allow us to give greater public exposure to pertinent issues. One of the most effective tools has been to let community members make the presentations and talk to the public. They seem to have greater success than we as professionals have at convincing their neighbors to be concerned about specific hazards and issues.

WILDFIRE HAZARDS AND PLANNING ISSUES

There is room for enhancements to the current system. In making any changes or developing a system from scratch, there are a number of concerns that need to be discussed. Some of them define new program objectives, others define the operating environment. An understanding of both are essential to implementing any new strategies.

Resources

In Jefferson County the cooperation between the County Planning Department, Fire Departments, and the Colorado State Forest Service have made it possible to implement some level of wildfire protection. There is much more improvement to be made, but without the mutual cooperation between these entities and others, it will be impossible to move forward.

Due to limited resources we are dependent upon the other sectors to also work towards these efforts and, where possible, provide resources. All potential resources should be sought out, including:

- National Fire Protection Association
- United States Fire Administration
- United States Forest Service, Ministry of Forestry in Canadian provinces.
- State forest service's, or department's of natural resources (refer to your states directory of organizations).
- Local fire protection entities, professional and volunteer.
- Universities
- Local fire associations or councils
- Insurance companies

Enforcement

The bottom line to implementing any policy is enforcement. In Jefferson County the enforcement task has been the responsibility of both Jefferson County and the Colorado State Forest Service. The Colorado State Forest Service makes field inspections and when the hazard is adequately mitigated it submits a letter to the Jefferson County Planning Department stating that all necessary actions have been taken. The county then records this with the appropriate subdivision file in the planning and building departments. The county is responsible for verifying that the work has been completed prior to issuing a building permit. Jefferson County will continue to depend on the Colorado State Forest Service to provide services to the county. Our enforcement process is dependent upon their participation.

Local and Private Interests

A common argument planning departments hear from the development community is that planning department processes and regulations cost too much, and that our processes and regulations make housing more expensive than necessary. It is true that local regulations do affect the cost of housing and it is important for local officials to be aware of this fact. It is untrue that regulations make housing unaffordable. The question of cost should be extended beyond the planning and development process into all sectors that implement processes and regulations for protecting lives, property and resources from wildfire hazards.

In the process of designing and implementing regulations it is necessary to determine who is paying, how much, and whether it is reasonable, or necessary. In addition we must also respond to our legislative charter. What are local officials responsible for, and are they acting responsibly towards meeting their legislative and legal mandates? Some questions that must be asked are:

- What is the cost to developers, and ultimately the consumer, for managing wildfire hazards?
- What is the cost to individuals and the general public for not managing wildfire hazards?
- Where do responsibilities lie for implementing wildfire hazard protection programs, and who is ultimately responsible?
- What are the legal implications of managing, or not managing, for wildfire hazards? Is there a legal precedent, and what are the legal liabilities?

Social Attitudes

There are a variety of public attitudes with which planners must contend. They affect how we work with the public and political leaders to effect change. They vary greatly and can be extremely difficult to overcome. The following is a sample of some of the more emotional attitudes that exist in Jefferson County:

- "The more trees the better"
- "More trees means more nature"
- "It won't happen to me", referring to most all hazards
- "Don't cut down that tree!" (There are places in our county that have covenants that restrict a home owner from cutting down living trees.)

A major attitude that must also be contended with is, "How much government is enough?" There is an attitude that government should allow people to live at risk from flooding, fire, and other hazards. It seems there are a number of people who would like to take the risk but would expect society to protect them if a disaster occurred. Government can not be so irresponsible and must implement regulations and standards that provide a reasonable level of safety to all its current and future citizens.

Design and Safety

What is the balance between design and fire protection? Throughout the development process there are conflicting positions regarding architecture, siting, and fire protection. Striking the appropriate balance can be more difficult than it might appear. The following are only a few of the typical conflict areas:

- Cedar shake roof shingles. A beautiful design feature, but left uncared for can result in serious fire hazard conditions. Even when cared for they represent a significant amount of fuel on roofs.
- How much vegetation and how close to leave vegetation next to structures. Frequently mountain / forest area design exhibits a desire to bring nature into the home. All too frequently it is coupled with the attitude that more vegetation is better. The result is homes with heavy fuel loads adjacent to homes, occasionally extending into or under decks, carports and the home itself.
- Road and driveway design. How to design roads and driveways that provide adequate access under emergency conditions, meet local standards, yet are visually aesthetic and environmentally sound.

Managing Small Parcels

The current process manages very small parcels of land at any one time. This is expensive and the overall effectiveness is not as great as if very large parcels were being managed. Without major social change, this situation is unlikely to change. Therefore it is necessary to find as many techniques as possible to increase effective forest management strategies for small parcels.

There needs to be clear understandings of dynamics and techniques that are effective when managing small parcels. For example, with small parcels, it is important to consider the adjacent property conditions, and the uncertainty of management on those parcels. It is probable that to adequately protect a site it is necessary to perform more extensive site modification than normal when there is an adjacent downslope condition that presents a severe hazard and no opportunity to manage it.

Long Term Maintenance

Long term maintenance of hazard areas is a major area of concern. The current process manages wildfire hazards at the time of development. The planning department responsibility typically ends after building permits are issued, with the exception of enforcing zoning violations. This makes it impossible at the current time for the county to implement long term mitigation of wildfire hazards.

To effectively implement long term wildfire protection there are several sectors that must address the problem. Each of these sectors has their own set of opportunities, constraints, and liabilities.

Local governments can assume greater responsibility for implementation and maintenance of wildfire hazard mitigation through a number of services they provide. Planning and zoning departments could implement hazard mitigation during the development process. Health department regulations might be able to enforce long term maintenance requirements. Sheriff departments might take more active fire marshalling and regulatory roles, especially as support organizations to local fire protection entities.

Local fire protection authorities, sometimes part of the local government, need to take greater responsibility not only for the initial mitigation and fire safety education but also for the maintenance of wildfire hazard mitigation. This might be accomplished through implementing new fire codes that address wildfire hazard issues, or extending fire safety regulations to include wildfire hazard concerns.

States might implement a fire marshal program and assign police authority to their state forest service, or other appropriate entities. State forest services can be a resource for information, coordination, and guidance of local governments, fire protection entities, and the insurance industry. This could be especially valuable to rural communities where low tax base prevents the local authority from adequately funding efforts to address wildfire hazards.

Insurance companies could also be more proactive at implementing strategies that encourage long term mitigation of wildfire hazards. This might be accomplished by providing discount incentives, similar to discounts provided for having fire extinguishers and smoke detectors in the home, to those who properly maintain wildfire hazard mitigation. They might require maintenance of wildfire mitigation as a provision for fire insurance.

It is unlikely that any one of these sectors alone has the statutory authority or political support to be particularly effective. It is absolutely necessary for these sectors to work together to determine the most effective way to deliver the service of protecting lives and property from wildfire hazard to their clients, the general public. Central to any effort is providing education between sectors and to the general public.

CONCLUSION

In Jefferson County we have managed to establish a procedure that is being implemented now that addresses the issue of wildfire at the development process. As a part of the development process we require that, where a hazard exists, a forest management plan be implemented prior to the conveyance of property ownership or just prior to building. A building permit will not be issued until a forest management plan is completed.

As a result, we believe that we are doing more to mitigate wildfire hazards in Jefferson County, lowering the risk of wildfire hazard to the homeowner. This also helps the local fire protection districts deliver better service to their constituents. Overall there is better forest management than if it were left totally up to voluntary action by citizens. There is a much better working relationship between the Colorado State Forest Service, fire districts, and the county. Spin off benefits for the Colorado State Forest Service and Jefferson County have been greater public exposure and opportunities to educate the public about wildfire hazards and other concerns.

In the future we hope to improve upon the existing system, formalizing the procedures that are currently done informally between Jefferson County and the Colorado State Forest Service. It is also our intent to solicit a more proactive relationship with fire protection districts. We need to find techniques that can be implemented that will ensure long term maintenance so that hazardous conditions don't recur.

It seems that some kind of hybrid system that use the best assets of local government, state government, local fire protection entities, and the insurance industry would stand the best chanc of succeeding.

The following is a basic framework for an implementation strategy:

1) During the development review process:

   - Planning department development review with initial hazard mitigation plan at the time of rezoning or plating. Field inspections by county, State Forest Service and Fire District.

   - Colorado State Forest Service provides forest management plan / Hazard mitigation recomendations.

2) Prior to development:

   - Inspection by Colorado State Forest Service and release of restrictions when hazard mitigation work is completed.

   - County enforces restriction through building permit issuance.

3) After development, owner occupied:

   - Fire protection entity with assistance from forest service inspects for wildfire safety.

   - Insurance industry requires hazard mitigation as a requirement for insurance, or for discount.

There are many possible variations on this theme. It is offered only as a starting point. In Jefferson County the Planning Department, Colorado State Forest Service and local fire officials have just begun to explore how we can more effectively implement wildfire protection strategies.

GUIDELINES FOR WILDLAND RESIDENTIAL SUBDIVISION DEVELOPMENT - AN ARCHITECT'S PERSPECTIVE

Albert Comly

INTRODUCTION

Subtitle - Eastern Architect in the West

Firm - Curtis, Cox, Kennerly

- 100 people
- Landscape Architecture, Master Planning

Got involved in wildfire initiative in the Spring 1986

UTLINE OF TALK

Architect

- Job

Influences on Architects work

- Codes/standards
- Design/materials selection

Conclude

- Action items
- What might be done

Architect Job/Task

- Works for client/owner (contract basis)
  - Not always the user
  - Scope of work
- Fulfills service in context of license (health, safety, welfare)
  - Examination - 9 parts over 3½ to 4 days
  - Nonlicensing
- Designs structure to house owners program (needs)
  - Other than houses - 5-foot outside walls
- Prepares documents for contractor to price and build (material selection included)
  - Don't supervise the construction
- Service ends with acceptance of structure by owner/client (maintenance begins)

PRACTICE FACTS

Architects over 80 percent practice in offices with five or less people

- Rugged individualism
- Architects education is general
  - Not experts in fire protection
  - Heavy reliance on codes

CODES/REGULATIONS

Zoning officers job: Everyone wants to be there because open and beautiful. Keep the same way after everyone who wants to be there gets there. Zoning officer must see to this.

DESIGN INFLUENCES

ZONING (legal issues - control by township or county. Mandate for fire department input?)

- Subdivision
- Land development

Governmental Restrictions

- Flood plain management (national maps - local approval)
- Wetlands and water course management (national maps - long approval time)
- Slopes, soil, and erosion control (local approval)
- Special (NJ Pinelands Commission)

Building codes

- Model (southern, UBC, BOCA)
  - Fire safety in structure (compartments, detection, extinguishment)
  - Natural forces (flood, earthquake, ice, snow, wind)

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utline of paper presented at the Symposium and orkshop on Protecting People and Homes from ildfire in the Interior West, Missoula, MT, ctober 6-8, 1987.

lbert Comly, Architect; American Institute of rchitects; Curtis, Cox, Kennerly, Philadelphia, A.

- Local codes and amendments
- Specific codes (NFPA, NEC, NFPA 101, NFPA 13)
- Maintenance codes (fire prevention, etc.)

Standards

- NFPA (over 700)
- ANSI (handicapped, structural performance, construction)
- NSTM (materials testing)

Environmental concerns

- Hazardous materials (cradle to grave, asbestos)
- Interior air quality (radon)
- Energy conservation

Local requirements

- Design covenants/deed restrictions
- Community architectural review (appearance, historical)

CODES

Approvals that are normally required in East

- Subdivision
- Land development
- Building permit
    - Utility application
- Construction inspection
- Occupancy permit
    - Tax roles
    - Financial packages

AIA policy for building performance regulations. Active participation by architect and public in consensus process.

- Set forth minimum standard for safety, health, and welfare in building construction
- Developed from rationally conceived criteria
- Designed to serve performance rather than prescriptive criteria wherever practicable
- Consistent in development, adoption, interpretation enforcement, and application
- Without favoritism or bias to any special interest
- Cost-effective in relation to public benefit.

ISSUES WORTH STRESSING

Local situation - uniqueness, requiring local solution
Importance of single agency review

- Knowing the hurdles up front

Fire company - importance of written response - to plan review items

- Its possible to have a bad outcome anytime. If only difference between success and failure is arrival of apparatus - that needs correction.

The wildlands problem is not the only problem facing architects; they must also deal with earthquakes, hurricanes, etc.

DESIGN/DETAILS

Conflict between sources (i.e. distance to clear around house)
Lack of available information
Influence of publications

MATERIALS SELECTION/DETAILS

Use of wood

- Self reliance (usually available on site)
- Indigenous (locally available)
- Cultural implications/background (associated with a home in the forest)

Wood shingles/shakes

- Florida - lost 200 houses without shakes or combustible siding.
- Does this mean that shakes are O.K.?
- If all shakes removed - would this conference end? No.
- Red cedar shingle and hand split shake bureau.
- 10-year study of fire retardant at Forest Production Laboratory in Wisconsin - must have retardant reapplied at some interval.
- Other methods - substate fire resistant.
- Decks, porches - need for treatment or use of other material.
- Overhangs, venting, impact on insulation.
- One hour - covering - What is that? Not non-combustible.
- Ratings - residential rec room NBS CFR. Based on time temp curve; 1921 test shows 4 hour wall breached in half an hour.
- It's a complex issue.
- Residence vs. larger buildings?
- Electronic media will allow greater flexibility in where we live.
- Remember - with all this design can be done without architects, according to the laws in some states.

WHAT CAN BE DONE?

Identify goals

- Risk acceptability vs. cost

- Community cost
- Infrastructure (roads, utilities)

Zoning, subdivision, land planning

- Identify and delineate hazard areas
- Consider incentives to allow recouping cost

Codes

- Incorporate in model codes, noncombustible roofs, etc. using performance standards
- Link amount of development with available protection
- Enforce knowledgeably and reasonably
- Recognize that wildfire challenges many existing concepts governing codes
- Consider maintenance, fire prevention code

Follow through

- Publicize subdivisions and development that emphasize wildfire design principles (not just to fire service--use architectural, construction, real estate and development, insurance, homeowner/popular publications)
- Compile design and maintenance data for all impacted parties (note what is being done about radon)
- Use of design constraints by Federal agencies in wildland/interface areas

Local and state AIA chapters can help. Engineering and landscape professional societies can help also.

THE IMPACT OF LAWS AND REGULATIONS ON BUILDING AND THE BUILDING PROCESS

David J. Dacquisto

ABSTRACT: Potential legal and regulatory approaches to reducing fire hazards in the wildland-urban interface are identified, including conventional methods and significant alternatives. Key issues surrounding the principal strategies are discussed, and likely effects on the building process are identified. Questions to be addressed in judging the need for and the desirability of regulatory intervention are also explored. The analysis suggests that traditional legal and regulatory strategies for dealing with such fires will often be less effective in producing change than the power of information, example and evolving standards of good practice.

INTRODUCTION

A large arsenal of weapons for mitigating the hazards posed by wildfires encroaching on residences in the wildland-urban interface have been identified at a series of conferences focusing attention on fires of this type. Many of the proposed strategies involve training, education, coordination, planning and research, and have only limited legal implications. However the possibility of explicit "legal" or regulatory intervention, in the form of amended building codes, zoning restrictions, or other legislation, is also frequently considered. Evaluation of the set of potential legal strategies is made difficult by the complicated nature of our legal system and our society. This paper describes a range of broadly-defined legal tools that may be available and discusses their impacts on building and on the community at large. It then identifies the types of obstacles and limitations that surround attempts to deal with this part of the fire problem through regulatory action. The goal is to provide a perspective on the range, nature and likely effects of laws or regulations that will guide their effective use alongside conventional firefighting tools.

LAWS, REGULATIONS AND THE WILDLAND-URBAN FIRE PROBLEM

Legal and Regulatory Tools for Fighting Fires

The use of laws and regulations as tools for fighting fires is nothing new. The "health and safety" protected by modern building codes relates predominantly to reducing the risk of fire. The regulatory approaches can generally be classified as "public" and "private" or quasi-public, and according to whether they affect fire safety directly through mandatory requirements or indirectly by altering private incentive structures.

Traditional forms of direct public regulation include building codes and zoning or land use requirements. These affect risk exposure at the dwelling-unit level and at the subdivision or even the community level. Both are mandatory in nature. Changes in zoning and land use practices, together with special prohibitions or requirements in building codes, are probably the most frequently cited examples of legal strategies for mitigating the wildland-urban fire problem.

There are other types of public regulation that have a broad but less direct effect on fire safety. State regulation of the business of insurance is a good example. Insurance premium schedules, discounts, and rating practices are generally subject to state review and approval. Insurance commissions have the power to implement rules producing financial incentives for homeowners designed to discourage particular types of risk exposure. Thus, insurance regulation can affect decision-making indirectly, by affecting market conditions. Insurance companies themselves can also take the initiative where they believe it is actuarially justified.

The classic form of legal action altering incentives involves specifying civil liability in greater detail, presumably giving property owners more responsibility for damage when their actions have contributed to a loss (this might rapidly feed back into insurance premiums). Or, property taxing systems could be used to assess incremental costs of fire protection where they are the

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Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

David J. Dacquisto is Deputy Director of the Economics and Policy Analysis Division at the NAHB National Research Center in Upper Marlboro, MD, a subsidiary of the National Association of Home Builders. Opinions expressed in this paper are those of the author and not necessarily of NAHB or its affiliates.

highest. Factoring in costs that go hidden under current systems helps to prevent consumers from facing artificially low prices for properties in high-risk environments. In this way, various parts of the system can contribute to realization of a market-based solution to the problem, without requiring special definitions of acceptable practice or a long list of official prohibitions.

Fortunately, there are opportunities other than formal action taken by publicly constituted bodies vested with regulatory authority. One type is embodied in consensus standards for design, materials, workmanship and product performance. Of course, some consensus standards find their way into law (model building codes are an example), but the majority are never used in this way. Nevertheless, in the building industry and many others their substance is reflected in evolving standards of "good practice." The power of example here can be more potent than the power of formal regulation. Builders will pay careful attention to meet perceived needs in order to satisfy consumers and remain competitive.

The second illustration of a private system of regulation involves the creation of covenants (enforceable deed restrictions) on real property. This form of "private law" can be used to address the risk posed by wildfires at a neighborhood level without the need for legislation. That is, unsafe land use practices can be prohibited by private agreement early in the development process in lieu of code or ordinance.

Ground Rules on the Availability of Legal and Regulatory Tools

n principle, there are few significant limits on he police power of the state to promote the ublic welfare by regulation, including building odes and zoning. So long as there is a clear onnection between the regulation and the nderlying public safety goal, the burden of ustification is largely met. There are also few nherent limits on the types of liability laws or nsurance incentives that can be established.

he simple basic picture is clouded substantially y several factors. One is the division of power nd responsibility across multiple jurisdictions. ederal agencies, state governments, state gencies, local governments, and planning boards ll have potential roles. There is no single ntity responsible for overseeing or coordinating ction; rather, each body works under its own set f powers and institutional restrictions. In many ases, the full range of potential powers are imply not made available to decision-makers. At ne extreme, there are large areas where no uilding codes or zoning ordinances are even in ffect, despite their availability in principle.

nce legal or regulatory action has been nitiated, the possibility of legal challenge and elay always remains. The constitutional limits n land use regulation are illustrated in First nglish Evangelical Lutheran Church of Glendale v. os Angeles County, 107 S.Ct. 2378 (1987), where the U.S. Supreme Court made it clear that a development moratorium ordinance denying all reasonable use of a property interest, even temporarily, could be grounds for awarding compensation to an owner. The moratorium in that case related to flood hazards, but the principle is relevant to other settings, including severe restrictions based on potential risk of fire. On the whole, First Church and other cases serve primarily as a reminder that there are limits on land use regulation. They place little or no restraint on the vast majority of conventional land use regulation, on building codes, or on the use of other legal and regulatory tools previously identified. In practice, the limits are set more by knowledge, public opinion, and the ability to achieve a consensus.

IMPACTS ON BUILDING AND THE BUILDING PROCESS

The range of potential impacts of legal and regulatory measures dealing with the wildland-urban fire problem is broad. Specific effects will depend on details of the particular measure in question. This discussion will identify general types of effects and the situations in which they can be expected to result, based on principles of economics and historical experience in various regulatory settings.

Ordinarily, impacts on building and the building process will be the result of impacts on consumers, developers, builders, manufacturers, and other parties. These points of view need to be distinguished in discussing the subject. Ultimately, of course, it is the impact on consumers that is of primary interest. The time horizon is also important: some impacts can be expected in the short-term, while others will naturally take longer to materialize.

There are two reasons for expecting the impacts on builders themselves of much likely regulation in this area to be small. First, builders are accustomed to functioning in an increasingly complex regulatory environment. Adherence to new building code requirements, zoning restrictions or other provisions of law are an inescapable part of doing business. Builders also generally operate in highly competitive markets, so increased production costs due to regulation are rapidly passed through to consumers of housing in the form of higher prices. They will tend to price out marginal buyers and shift others towards resales, but that is not the same as builders absorbing cost increases out of pocket. Over the long run, impacts will instead fall on consumers, owners of undeveloped land, and the growing community itself.

From the consumer's standpoint, many regulatory measures would lead to direct cost impacts. These would include extra costs for building materials and labor, as well as extra financing costs and property tax liability. Insurance reform would obviously affect the cost of property insurance. Zoning and subdivision-level regulations that reduce density and increase infrastructure costs per housing unit for roads or utility services, or dedicated open spaces and prescribed land and vegetation management practices would generate corresponding cost impacts. Of course, costs are not the only impact. The regulations would also affect the physical environment surrounding the buildings. This is their very purpose.

Increases in the cost of housing due to regulation have traditionally concerned the building industry as well as others interested in the availability of decent, affordable housing on a broad scale. Rising costs increase down payments and monthly payments, making qualification for mortgage loans more difficult. Such increases can drive less affluent consumers entirely out of the market for entry-level housing. Yet, it appears that considerations of affordability could be less important with respect to regulation here than in other current settings. This is partly because of the limited scope and local nature of the problem: most housing simply should not be affected by well-designed regulations. Also, many (but not all) of the homes at risk are luxury homes, second homes, or vacation homes where affordability is not the most important consideration.

Costs such as those identified above constitute the initial round of economic impact. They will trigger a further set of economic adjustments, or second-order impacts, that can take many different forms. Examples include locational shifts in building activity (depending on the scope of the regulation), and changes in land values as the profitability of development changes. Their magnitude generally becomes smaller as they become more remote from the particular law or regulation involved.

The economic impacts of regulation are neither good nor bad in and of themselves. Any such judgment requires evaluating their effect on risk exposure and the resulting implied benefits. In principle, where they are "cost effective" they can be good policy, while where they are not cost effective, they are economically inefficient and objectionable.

A further class of impacts might be called "inadvertent." In attempting to solve one problem, it is often possible to make another one worse. For example, it could be disastrous if homes that were sited to reduce the risk of fire suffered from increased risk of flash flood, avalanche, or other natural hazards. It is easy to lose sight of the fact that the wildland-urban fire problem is symptomatic of the need for an integrated approach to hazard management in certain special types of residential occupancies.

The remaining impacts to be discussed are no less important than the others. Building takes place in an environment that is larger than the specific words of laws and regulations. This environment can be shaped informally, by example from other communities or jurisdictions, and by consensus standards that do not have the force of law. In many ways, these forces, and not the technicalities of statutory language, serve to drive events. Good practice can involve adherence in substance to requirements that are not necessarily legally enforceable, and the impact of a law, a regulation or a standard often depends on its power to catalyze change outside its original domain. This is only enhanced by the power of modern mass communication. Where the problem and the solution are clearly understandable, positive change can be achieved with a minimum of formal intervention.

DEVELOPMENT OF A REGULATORY AGENDA

Moving forward towards regulatory solutions to address the wildland-urban fire problem is no simple task. For while the power of the state to regulate is very broad, its willingness to do so is often much more narrow. Proposed regulatory action will be subject to close scrutiny by many parties, some of whom will not understand or appreciate the issues involved. Multiple bodies will sometimes be involved in setting policy, each with its own constituency and institutional objectives, some of which have little to do with public safety as such. Thus, achieving regulatory change can prove very difficult in practice. The procedural requirements often include explicit factfinding and public hearing on the effects of specific proposals. And implicit in the final decision is the political task of setting of overall priorities: deciding which problems merit action now, and which can be deferred until later.

The most significant obstacle to regulatory change here may be the perception, valid or invalid, that residential fires in the wildland-urban interface are not now a major problem, either in absolute terms or by comparison with other types of fire. The perception rests on the finding that for the United States in 1985, wildfires caused 44 fatalities and destroyed or damaged 1400 homes. This is around 1% of all residential fire fatalities. More lives can easily be lost in one large hotel fire; according to the National Weather Service more people are killed by lightning in an average year. The benchmarks will vary from one setting to another, but the recurring question will be whether public or private funds spent on reducing this risk might be better spent on more general fire prevention, or for other purposes. On the other hand, the disproportionate property losses associated with these fires (hundreds of millions of dollars each year) must also be considered. Additional factors such as growth in losses or risk of major disaster are potentially relevant to setting policy, but are usually less compelling than demonstrated loss experience. A solution requires identifying narrow classes of high risk in advance.

An important possible goal to keep in mind when pursuing reform is the creation of an environment in which normal market forces can work to eliminate a problem, rather than trying to address it by affirmative regulatory requirements. That is, work to ensure that insurance incentives are not distorted, that taxing policies reflect costs of service, and that risks are known and understood. Then rely on the natural operation of the market to bring about a situation in which risks reflect the preferences of the consumers whose tastes led them to this special environment in the first place.

In formulating an agenda for regulatory change, the use of less overt methods for achieving the desired ends should not be overlooked. This includes fostering the development of consensus standards and model approaches that address this problem along with others. The building industry participates in and has considerable respect for this process. As previously mentioned, this approach can be effective in altering general practice, even where it is not official law. It is also groundwork that can be repaid many times over in facilitating reform at the local level. Finally, it is easier because there are relatively few bodies developing consensus standards compared to the fifty states and thousands of local governments that ultimately enact the official rules.

Among the other factors to consider in fashioning regulation is the question of focusing on new housing as opposed to global risks, or all housing. By their nature, most building codes and standards affect new construction almost exclusively, while the current fire risk clearly lies entirely with existing structures. The long lives of buildings and slow turnover of the housing stock mean that at best a strategy targeted strictly at new building could take decades to produce detectable benefits, without affecting risks within the current stock. Assuming that fires in the wildland-urban interface are a serious problem today, calling for near-term action, then solutions dealing with risk to all affected structures, new and existing, offer a faster way to achieve tangible benefits than those focusing on new buildings alone. This points to the importance of regulating activities and practices such as outdoor burning and vegetation management that contribute to the problem but have nothing to do with housing.

Whatever the future of legal or regulatory change in this area, it is possible that the most important opportunity afforded by this problem involves drawing attention to the risk of fire, through vivid media coverage of wildfires presenting catastrophic hazards to residential properties. This offers chances to provide large audiences with information on how to prevent or deal not just with outdoor fires, but also with the more common types of residential fires.

SUMMARY AND CONCLUSIONS

Several types of legal and regulatory strategies are available for mitigating the risk of wildfires to residences in the wildland-urban interface. In addition to traditional tools like building code requirements and zoning ordinances, there are several less formal methods for achieving regulatory effects, including insurance reform, private covenants and consensus standards. Legal and regulatory steps, where effective, are bound to have impacts on consumer prices similar to those resulting from other types of economic regulation. Whether the net impacts are beneficial or detrimental depends entirely on the regulation and the surrounding circumstances. A regulatory strategy need not involve dictating technical solutions. It is sometimes simpler to focus on eliminating distortions in underlying economic forces, allowing the market to seek its own solution.

Formal action in this particular area has been slow to emerge. The simplest alternative here requires working in a voluntary, consensus context to define the problem and specify practical remedies systematically before broader audiences. Organizations, procedures and tools for this type of change are already in place.

SESSION 6

Allen Masters, Moderator
Regional Forester, Parks Canada
Calgary, Alberta

THE WILDLAND RESIDENTIAL FIRE PROBLEM: A FIRE ENGINEER'S PERSPECTIVE

Brooke B. Smith, Jr., P.E.

ABSTRACT: The role of the fire protection engineer as a member of the development team designing residential property in wildland areas is presented. Integrated design using the fire protection engineer to review aspects of prevention design and to develop recommendations for protection design is shown to be effective. The design of water supply to the wildland residential development is especially important and the fire protection engineer's contribution in this area is explained in detail.

INTRODUCTION

Understanding the wildland residential fire problem and helping in the development of solutions to the problem are somewhat new and yet very challenging areas for the fire protection engineer. The engineer's established scope of practice however, of how to safeguard life and property from the hazards of fire is certainly adaptable to this problem (Society of Fire Protection Engineers 1985). By simply changing the traditional scope slightly to read:

> ...safeguarding residential life and property from the hazards of wildland fire...

certainly brings into focus the subject situation, and sets the challenge for today's fire protection engineer specializing in the residential wildland fire problem.

As with any profession, the practice of fire protection engineering may be directed in many areas including design, enforcement, research, teaching and training. All of these areas of practice have application to the residential wildland fire problem, but design is the area selected for additional discussion.

Design for wildland fire safety should be done as part of the overall property development process if it is to be effective and economical, and all members of the development team should incorporate emergency fire conditions as an integral part of their development activities. Failure to design in adequate provisions for the prevention, control and extinguishment of wildland fires tends to invite their frequent occurrence with the consequent osses of life and property. In addition, wildland fires have deleterious effects upon the environment causing damage to the very surroundings that have attracted residents to the development in the first place. Add-on fire safety, planned after a development has been designed or constructed, is inherently more expensive and generally less effective than that engineered as an integral part of the total residential development (fig. 1).

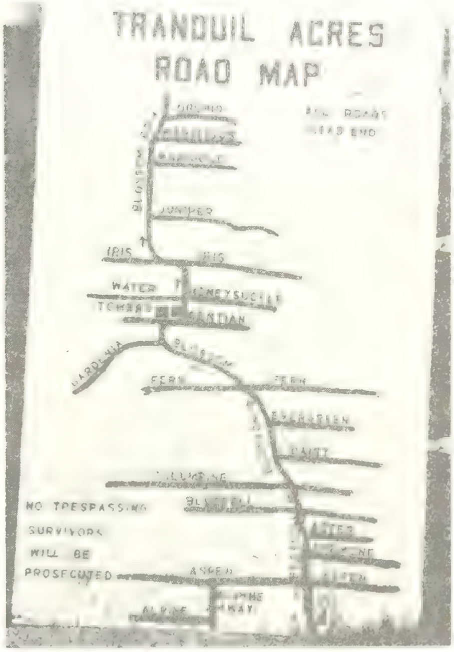

Figure 1--Road map of wildland residential development indicating that all roads are dead end. It would be most difficult to improve access now since all of the roads are constructed and lots platted.

THE DEVELOPMENT TEAM

Residential development in wildland areas throughout the interior west is in many areas, already a very complicated process. The developer is required by law in many cases, to surround himself with surveyors, planners, architects, engineers, lawyers, and financiers. This large and expensive group of consultants is needed to deal with current subdivision regulations, zoning rules, building codes and fire codes so that the developer can simply get to the point where he can start to sell property and construct homes. The mere thought of adding a fire protection engineer to help deal with the wildland fire problem would probably be frightful to the developer if he were not already somewhat numb from the whole process.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the nterior West, Missoula, MT, October 6-8, 1987.

Brooke B. Smith, Jr., P.E. is President of Aspen ngineering, Inc., Civil and Fire Protection Woodland Park, CO.

What is hoped for however, is that by adding the fire protection engineer to the development team, the developer is not simply introducing just another cost center. Hopefully, he will be giving the overall program of subdivsion fire safety, which already has to be considered, coordination and direction. The fire protection engineer's role with the project team would involve the development of overall subdivison fire safety measures which would necessarily include those related to the wildland fire problem.

Implementation of these fire safety measures can reduce the exposure of life, property and resources to an 'acceptable level of risk' and provide 'defensible space' that could protect residents and enable firefighting equipment and personnel to operate during a wildfire (California Department of Forestry 1980).

THE FIRE PROTECTION ENGINEER'S ROLE

The wildland fire problem is generally known not to have a single solution due to the hazards, risks and complicating factors. A combination of remedies is usually required to achieve any reasonable degree of fire safety for structures in or near wildland areas (Moore 1981). The fire protection engineer's involvement with the development team should be viewed as helping the developer with formulating these remedies.

In general, project involvement by the fire protection engineer would typically include work described by activity in the following areas:

Prevention Design

This involves efforts to 'design out' of the development as many hazardous conditions as is prudently possible in order to reduce the chance that a loss will occur. Prevention design by the fire protection engineer is ususally accomplished through particpation with the development team in the following areas:

Establishment of Fire Hazards--The natural fire hazards of a wildland area are relative and generally vary with the fuel loading, ground slope and weather. These hazards are frequently quantified by local forest officials into a classification system that defines severity zones. In states such as Colorado and California, these severity zones have been mapped. The fire protection engineer should use this data to map the specific hazard severity zones for the development. If hazard classification systems or mapping do not formally exist, the fire protection engineer should seek help from local forest officials to establish severity zones and prepare maps for the property under development (fig. 2).

The Fire Hazard Map for the development becomes a very important document to be shared by the entire development team during the planning process.

Reduction of Fire Risk--The basic fire prevention problem in any environment is the separation of flammables and combustibles from sources of ignition. This is especially true in the wildland situation where most of the fire risk is man-made.

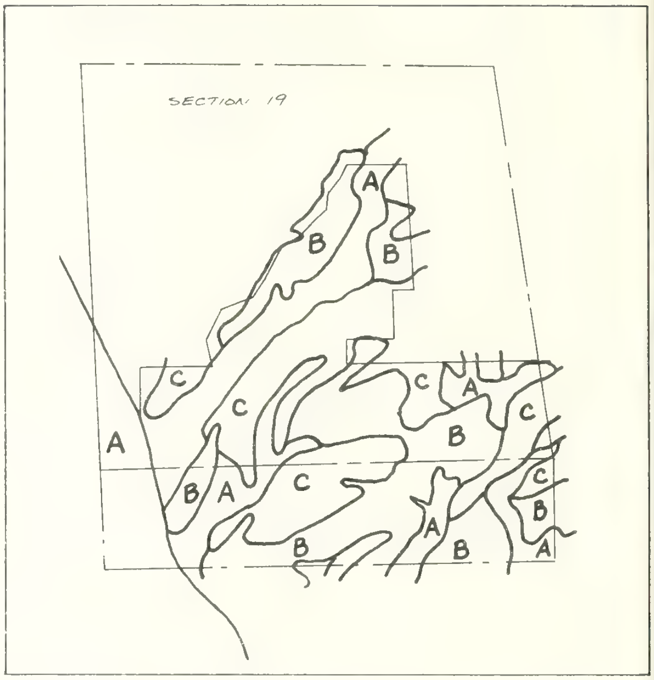

Figure 2--Wildland Fire Hazard Map of proposed development based on data from the Colorado State Forest Service. Scale: 1 inch = 2000 feet. Hazard Classes: A--Low Hazard; B--Medium Hazard; and, C--Severe Hazard.

The fire protection engineer should provide recommendations to the development team addressing underground electric lines, protection of flammable liquid and gas storage tanks and residential clearance to native vegetation (fig. 3).

Review of Development Design--The design of the development encompasses many aspects and is generally a team effort of planners, engineers and surveyors. Most communities also have adopted subdivision regulations that set certain 'minimum' requirements for lot density, building spacing, access roads, parks and greenbelts. In many cases, these 'minimums' are followed by the development team without regard to the wildland fire problem.

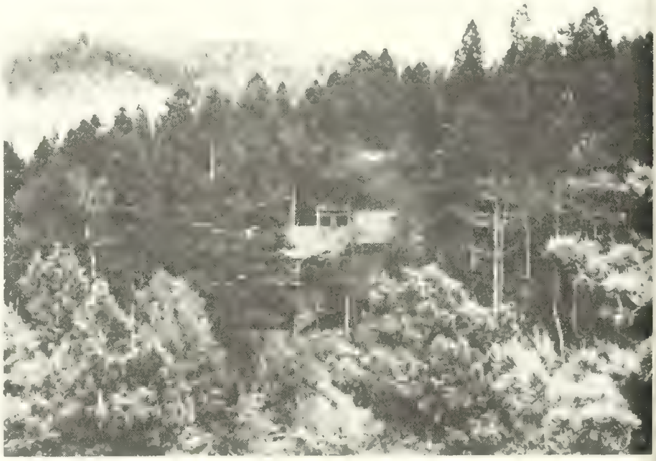

Figure 3--Obvious example of inadequate clearance from residential building to native vegetation.

The fire protection engineer, using the Fire Hazard Map as discussed above, needs to provide input during the early phases of development design so that 'minimum' requirements are modified if needed to compensate for the wildland fire hazard.

If the community in which the residential development is being constructed has not adopted subdivision requirements that meet the basic needs for development in wildland areas, the fire protection engineer should recommend that such generally available standards be reviewed, modified if necessary, and then adopted by the developer for the project. References for such standards include publications by the U.S. Forest Service, California Department of Forestry and the Colorado State Forest Service.[1]

Review of Building Construction--The building construction phase of a residential development may or may not be undertaken by the property developer, by whom the fire protection engineer is usually employed. However, since the design and construction of buildings is such an important part of the residential wildland fire problem, it is important for the fire protection engineer to participate in this phase of the development if at all possible. One way to help control the construction of buildings, even if the developer is not the builder, is through the use of deed restrictions or covenants prepared by the developer as part of the planning process for his subdivision.

Of prime importance are materials acceptable to the fire protection engineer for building roof coverings. Also of importance are considerations of glass areas, exterior siding, overhangs, decks and stilt construction (fig. 4). The fire protection engineer should recommend to the development team that design and materials for building construction in a wildland area be consistent with generally available standards. References for such standards include publications by the U.S. Forest Service, California Department of Forestry, and the Colorado State Forest Service.[1]

Protection Design

This involves efforts to 'design into' the development fire safety systems to limit damage and loss, should an incident occur. Usually, this design is not essential to the operation of the development, but it is essential to the preservation of life, property and resources under fire conditions. Protection design is almost always under the direction of the fire protection engineer, and the preparation of detailed drawings is usually done in cooperation with the remainder of the development team. Included are considerations of:

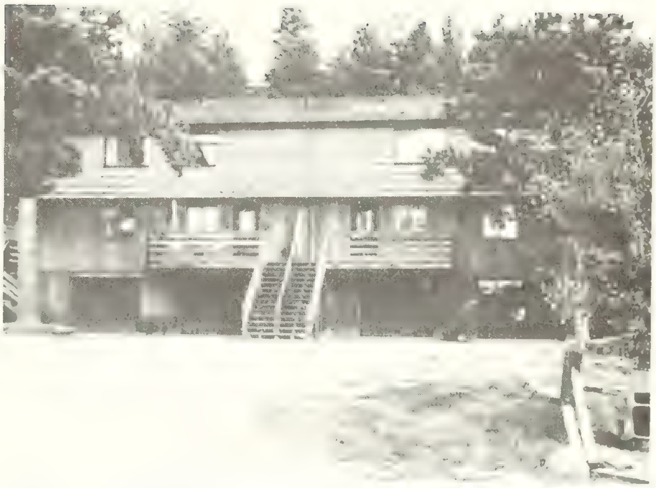

Figure 4--Multifamily dwelling in wildland area with wood shingle roof and siding.

Water Supply--Water, which is available in sufficient quantity and for the time required, is still the most effective fire safety measure for combating both wildland and structural fires. Therefore, a large, dependable source of water above that required for normal daily domestic purposes should be provided at the time the development is planned (Alger 1971, National Fire Protection Association 1985). The design of this water supply has to be considered one of the most important contributions the fire protection engineer makes to the development. The supply can take on several forms depending on the domestic water arrangements.

If the subdivision is to be supplied by a connection to a municipal water system, then the design usually only involves extensions to the distribution system and location of valves and hydrants (fig. 5). Depending on location however, the design may include provisions of booster pumps, storage tanks or pressure reducing stations. If the subdivision is to be supplied by a private system that is only capable of domestic flows or if individual homes are supplied by wells, then the design may involve the placement of water storage cisterns and the development of suction connections to ponds or streams (fig. 6).

Water supply is considered so important to the development and the fire protection engineer's responsibility so significant that this topic will be covered in greater detail hereinafter.

Fire Station Placement--In large developments or those somewhat remote from existing fire stations, local laws may require dedication of a site within the development for a new fire station. The fire protection engineer should work with the fire suppression officials who will be responsible for the development in selecting an appropriate site. If such local laws do not exist, but the

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[1] Moore, Howard E. 1981. Protecting residences from wildfires: a guide for homeowners, lawmakers, and planners. Gen. Tech. Rep. PSW-50. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 44 p.

California Department of Forestry. 1980. Fire safe guides for residential development in California. Sacramento, CA: California Department of Forestry. 32 p.

Coulter, J. Bruce. 1980. Wildfire safety guidelines for rural homeowners. Fort Collins, CO: Colorado State University, Colorado State Forest Service. 23 p.

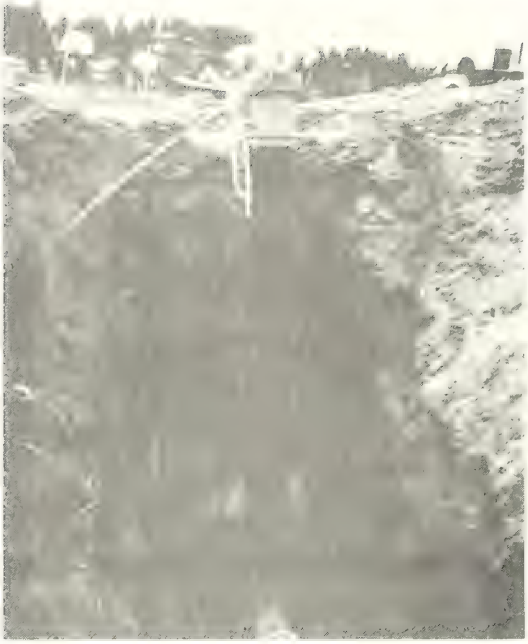

Figure 5--Addition of fire hydrant by extension of existing municipal distribution system.

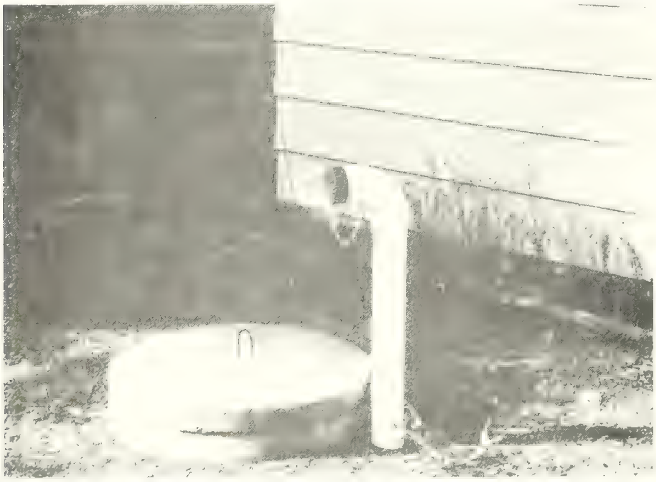

Figure 6--Underground water storage cistern with fire department pumper connection.

development is over 640 acres in size or over 4 miles from the nearest fire station, the fire protection engineer may still want to recommend to the development team that a fire station site be dedicated (Moore 1981).

Emergency Access--As discussed previously in the section on Development Design, access is one of the important aspects of development in wildland areas. Of course, access designed in accordance with proper standards is desired, but occasionally (usually due to topography) only one form of regular access is possible. In these cases, the fire protection engineer would be responsible for the possible development of emergency access routes for use during a wildfire or other emergency. These may involve steep connections to lengthy cul-de-sacs, or tie roads through adjacent property not available for normal traffic (fig. 7).

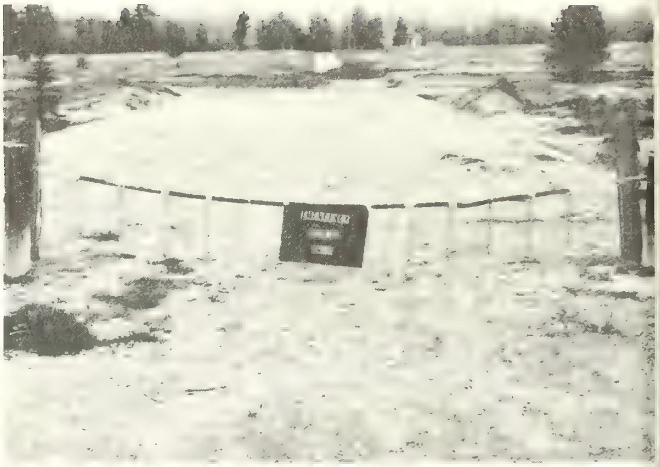

Figure 7--Emergency access to residential subdivision using 'push to break, weak link chain' as barricade.

Fuel Breaks--The locations of both perimeter and local fuel breaks in the development require consultation between the fire protection engineer, local forest officials and the rest of the development team. Frequently, golf courses, greenbelts, parks and open space that are either required by law or simply planned as an amenity by the developer, can be arranged to function as fuel breaks. These spaces, especially perimeter fuel breaks adjacent to forest areas, require dedicated easements for fire vehicle access. Local fuel breaks around individual residences should be required in deed restrictions or covenants should the developer sell land for building by others.

Interior Dwelling Protection--The Uniform Building Code is in use throughout the interior west and it has a number of requirements for interior fire protection of all dwellings. These include the current provisions of smoke detectors and the proposed provision for mandatory automatic sprinkler systems. The requirement for automatic sprinklers in residential properties is getting more attention especially with the development of quick response sprinklers and the ability to use plastic materials for sprinkler piping (National Fire Protection Association 1984).

If automatic sprinkler systems are required or anticipated in the development, the fire protectio engineer should take this into consideration when designing water supplies. Some local fire jurisdictions have taken the position that provision of mandatory automatic sprinklers in residences will reduce the demand of fire service personnel required due to reduced water supply requirements. While the provision of sprinkler systems will reduce the water supplies needed for interior protection, the fire protection engineer should carefully consider if such reductions can be made to the system without impacting the needed fire flows for wildland fire control.

THE DESIGN DOCUMENTS

When dealing with the wildland fire problem, it is of utmost importance for the fire protection engineer to establish the bases or philosophy for the above prevention and protection design recommendations. This philosophy should consider the wildland hazards and risks in concert with the developer's preferred master plan and all applicable local laws and codes. The engineer must realize that not only are his services of immediate cost to the developer, but usually his recommendations will, in one way or another, reduce the future amount of money to be realized from the development. For this reason, the fire protection engineer should make his recommendations in writing during the preliminary work on the development's master plan so that the development team will have time to consider the impact of the fire safety measures proposed.

This written report or design document should describe the proposed development, the wildland hazards and risks, and the proposed prevention and protection recommendations. This preliminary document should be circulated to the developer and all members of the development team first, so that all 'in house' comments can be addressed. Hopefully, a consensus report from the development team can then be finalized. This document is then sent to local forestry officials and all development legal authorities (city, county, etc.) for review and comment. It may take several revisions for the design document to be accepted by all parties, but once accepted, implementation of the proposed designs can take place.

The acceptance of this design document is a most significant step for the fire protection engineer. Many of the items of prevention and protection design are covered sufficiently in this document so that implementation by others on the development team is rather straightforward. For example, the development planner can simply incorporate on his plat the desired location of greenbelts and fuel breaks; the development attorney can prepare subdivision covenants relative to acceptable residential building materials; and, the development surveyor can lay out the desired locations of emergency access roads.

The design of the water supply system for the development however, may require significantly more involvement by the fire protection engineer. Although his responsibility in this effort is usually directed at basic design and definition of scope of work to the development civil engineers, the fire protection engineer should carefully review all civil construction drawings in order to be certain that the requirements of his basic water supply design are being met. This would include review of the fire hydrant and valve placements, distribution pipe size and placement, storage tank size and placement, and any required pump specifications. Following completion of construction, local fire authorities may want selected fire flow tests of the completed system performed to verify conformance to the fire protection engineer's basic water supply designs.

WATER SUPPLIES

The design of water supplies to meet a fire emergency in a development is normally based on the requirements for fighting an interior residential fire. In most cases, this design criteria is adequate for protecting the building from an encroaching wildland fire as well. This is because the interior requirements reflect both the financial property risk and multiple life risk (Moore 1981).

Of course, part of the problem with wildland areas is that sufficient water may not be available for either interior or exterior protection. Many homes are supplied from individual wells or 'domestic only' central systems. This situation is viewed as being on the decrease however in most new residential developments in the interior west due to increased fire awareness and local laws. Many communities have adopted the Uniform Fire Code which requires adequate water supplies to meet building structural fire demands.

Needed Fire Flows

After carefully reviewing the development for density, building spacing and building materials, the fire protection engineer should establish the needed fire flow for the 'typical' residential building proposed for the subdivision. Guidelines for calculating needed fire flows are published by several sources, with that from the Insurance Services Office (ISO) used most frequently.

A typical one or two family dwelling not exceeding two stories in height with at least 11 feet between buildings would result in an ISO Needed Fire Flow of 1000 gallons per minute (gpm) at a minimum residual pressure of 20 psi (Insurance Services Office 1980).

The water supply system is also required by ISO to have the Needed Fire Flow available for a minimum of two hours. In this case that calculation would yield a volume of 120,000 gallons of water that should be reserved for fire protection use above that required for normal daily domestic purposes (fig. 8).

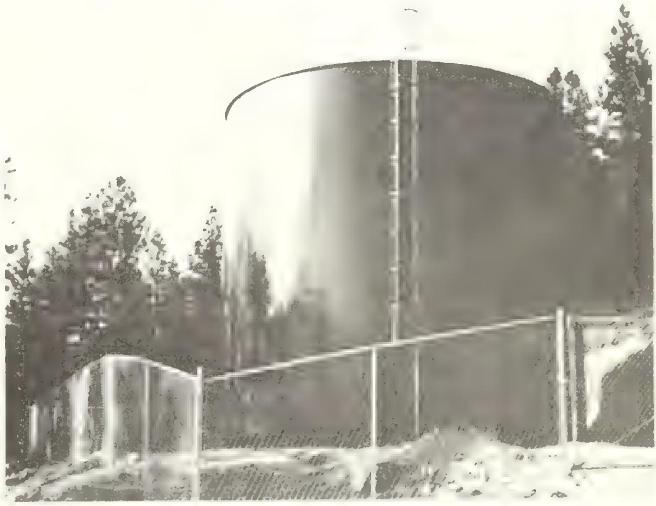

Figure 8--Water storage tank sized to provide sufficient capacity to meet the required 2 hour water demand for fire protection. This volume is required in addition to that necessary for domestic purposes.

As stated above, Needed Fire Flows calculated for interior building protection are also generally acceptable to meet the danger to the development from wildland fires. This assumption should be carefully evaluated by the fire protection engineer along with local forest and fire suppression personnel. It is possible that extreme wildland conditions or subdivision configurations may require fire flows larger than that required by ISO for a residential interior fire.

Available Fire Flows

After determining the above requirements for needed fire flows, the fire protection engineer should then determine available supplies. If the proposed development is to be served by an extension to an existing water supply, a fire flow test should be performed close to the proposed extension location (fig 9). The data derived from the flow test will establish the Available Fire Flow of the existing system at that location, which is the gallons per minute of water that can be provided at a minimum 20 psi residual pressure.

The proposed water distribution system is then analyzed to determine the Available Fire Flows present throughout the development. This analysis frequently utilizes computer programs to assist with the calculations necessary for multiple loop water systems. Unless the Available Fire Flow exceeds the Needed Fire Flow at all locations, adjustments to line sizes are sometimes required to reduce friction losses. In some cases, a specific need may be identified for either booster pumps or pressure reduction stations.

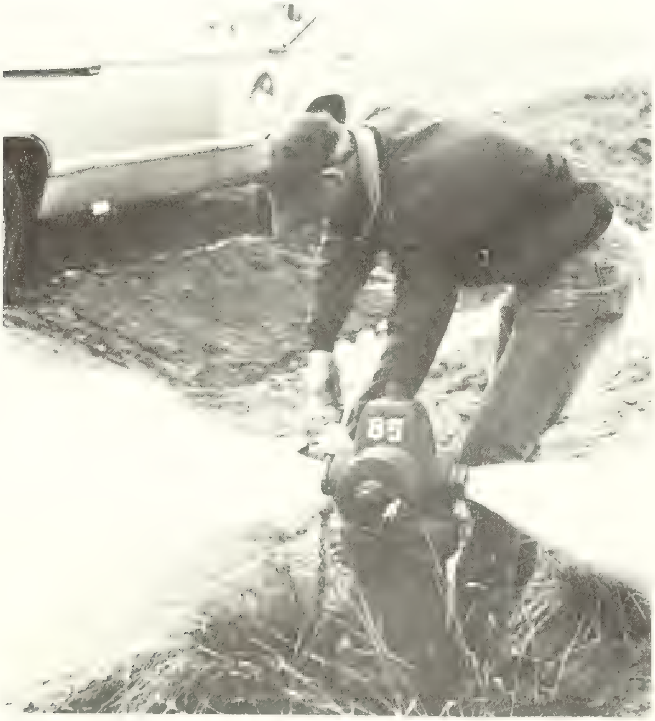

Figure 9--Fire flow test in progress. Tester is taking pitot pressure readings at the flow hydrant to determine the quantity of water (gpm) discharging from each hydrant outlet.

Distribution System

The distribution system should be arranged with multiple loops of piping, eliminating as many long dead ends as possible. This is almost always to everyone's advantage (including the developer) because friction loss is lowered and frequently the pipe line can be reduced in diameter (minimum 6 inch). Not only does this reduction save the developer installation cost, but the looped system is also more hydraulically efficient and dependable. In developments with cul-de-sacs, a good design technique is to extend the possible dead end water main along lot lines (in dedicated easements) to complete a loop arrangement (fig. 10).

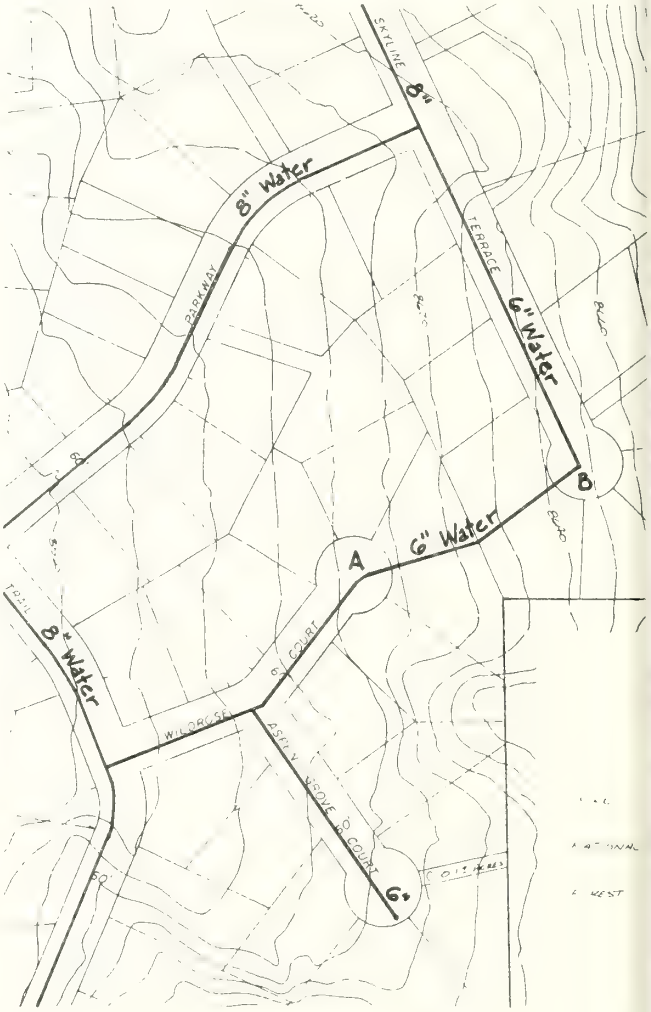

Figure 10--Portion of a water distribution map for a residential development in a wildland area. Note the loop formed by extending the water main down the property lines between points A and B.

Fire hydrant placement is also covered by ISO guidelines and in general, the fire protection engineer will find these suitable for development in wildland areas. Fire hydrant spacings of 300 to 500 feet as measured along the road frontage are common and acceptable for most developments. All hydrants should be provided with large diameter fire department pumper connections as well as smaller hose connections.

The distribution system should also incorporate an adequate number of line valves to isolate sections of the system for repairs. The fire protection engineer should provide enough valves so that no more than one or two legs of a loop are out of service at a time. The maximum line length between valves should be limited to 1200 feet.

CONCLUSIONS

As the problem of residential development in wildland areas continues to be addressed, it appears that the contributions from fire protection engineers can be of significance especially as a member of the development team. Although this position establishes the developer as the client, it also puts the engineer in a position to substantially contribute to the design of the project at a time his skills can best be utilized. In addition to loyalty to the developer as his client, the fire protection engineer, through society ethics, is also dedicated to the safety, health and welfare of the public (Society of Fire Protection Engineers 1985).

With this dedication to public safety, the fire protection engineer is viewed as functioning as somewhat of a legitimizer for the developer, and as such is considered a critical member of the development team. In this role, the fire protection engineer can help bridge all sides of the Wildland/Urban Fire Triangle (fig. 11). This participation should help lead to solutions of the residential wildland fire problem.

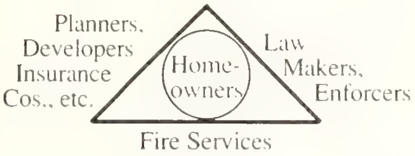

Figure 11--The wildland/urban fire triangle (National Wildland/Urban Fire Conference 1987).

REFERENCES

Alger, R. S. 1971. The great Oakland, Los Angeles, and San Diego fires, September 22-29, 1970. Silver Spring, MD: U.S. Naval Ordance Laboratory. 44 p.

California Department of Forestry. 1980. Fire safe guides for residential development in California. Sacramento, CA: California Department of Forestry. 32 p.

Insurances Services Office. 1980. Fire suppression rating schedule. New York, NY: ISO Commercial Risk Services, Inc. 34 p.

Moore, Howard E. 1981. Protecting residences from wildfires: a guide for homeowners, lawmakers, and planners. Gen. Tech. Rep. PSW-50. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 44 p.

National Fire Protection Association. 1984. Installation of sprinkler systems in one- and two-family dwellings and mobile homes. NFPA 13D-1984. Boston, MA: National Fire Protection Association. 18 p.

National Fire Protection Association. 1985. Homes and camps in forest areas. NFPA 224-1985. Boston, MA: National Fire Protection Association. 17 p.

National Wildland/Urban Fire Conference. 1987. Wildfire strikes home! Boston, MA: U.S. Department of Agriculture, Forest Service, National Fire Protection Association, U.S. Fire Administration. 90 p.

Society of Fire Protection Engineers. 1985. Yearbook. Boston, MA: 182 p.

FIRE-SAFE BUILDING PRODUCTS: RESEARCH FINDINGS

Susan L. LeVan

ABSTRACT: The Forest Products Laboratory (FPL) has served as the national center for wood products research since 1910. The Fire Safety of Wood Products research work unit of FPL is generating new technologies to improve the fire safety of wood-using construction. Our fire research program concentrates on fire growth, fire endurance, and fire retardants. This paper discusses the research activities in each of these areas.

INTRODUCTION

Designing a fire-safe building in urban areas depends on the intended occupants of the building and the location. Building codes limit the potential for fire damage by considering the occupants and the location (Spelter and others 1987). Fire performance requirements for materials for a hospital or nursing home differ from those materials required for a commercial shopping center. In the wildland/urban interface areas, homes and buildings should be constructed using this same philosophy of matching probable risk caused by the location with the level of acceptable hazard for the occupants. If the risk is high, then the level of acceptable hazard for the occupants may dictate noncombustible building materials, aluminum fire shutters, and other precautionary measures. However, if the risk is low to moderate, then homeowners have more options in selecting the building materials, including wood.

Although wood is combustible, the esthetic and rustic values of wood are what many homeowners in the interface area want. However, the hazard of fire in these areas indicates that compromises must be made between what is safe and what is desired. Today we have many design procedures which can be used to reduce the hazard to wood building materials during fire. Certain chemicals can be applied to wood to reduce its flammability. Such research information is applicable to structures in the wildland/urban interface area to improve the fire performance of wood construction materials. This paper addresses the ongoing research at the FPL to improve fire performance of these wood products.

BACKGROUND

The Forest Products Laboratory, Madison, WI, has served as the national center for wood products research since 1910. Over the years, the FPL has continued to improve its research capabilities to remain a leader in wood research. The underlying mission of the FPL is to improve utilization of wood through research that leads to improved management and use of the timber resource, thus meeting the needs of the United States and contributing to the international community. Inherent in this fundamental philosophy is the criterion that FPL research properly address both the current and future needs of its user groups.

At the FPL, my research work unit's mission is to generate technology for improving fire safety of wood-using constructions. Because of the large us of wood products in commercial and residential applications, architects and engineers must be concerned with the performance of wood materials i a fire and, in particular, how these materials wil affect the life safety of occupants and firefighters. To understand the fire performance of wood materials, we need to know how wood products contribute to the growth of a fire and about their ability to maintain structural integrity during a fire. Once these performance properties are known, the potential risk of using these materials can be addressed.

FIRE RESEARCH

Our fire research program concentrates on three areas: (1) fire growth, (2) fire endurance, and (3) fire retardants. Fire growth is concerned with the initiation of the fire, its spread and propagation. Fire endurance pertains to the ability of the structural assembly to maintain structural capacity. Fire retardants are chemicals added to wood products to alter their flammability. This paper describes some of the current and planned work in each area.

Fire Growth

Computer fire growth models describe the fluid dynamics which occurs in a room with a fire and the interaction between the fire and the various materials. These models use the input properties described below to generate a probable sequence of events and to describe the growing temperature development within a room from initiation, propagation, and finally flashover. However, these models are in their infancy, and considerable more research is necessary to improve their accuracy.

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Susan L. LeVan is Project Leader, Fire Safety of Wood Products, Forest Products Laboratory, U.S. Department of Agriculture, Forest Service, Madison, WI.

At FPL we are evaluating the capabilities of many of these fire growth models that were developed at the National Bureau of Standards, Center for Fire Research (Bukowski 1986; Jones 1984; Mitler 1985) and at Ohio State University (Sauer and Smith 1983). We use these models to assess the potential risk involved with particular designs or materials. Fire growth models also can be used to improve the fire safe design of a building such as the location of windows, doors, and smoke detectors. Currently, we are building a room to conduct full-scale room burn tests. These room burn tests are used to verify the fire growth models.

To describe how wood contributes to the fire growth process, we measure the heat release rate, the smoke generation rate, and the flame travel rate, all as a function of the external properties such as moisture content, density, and the imposed heat flux. We measure these properties on small-scale equipment and on full-scale assemblies. Ongoing work at FPL aims at defining these properties so that we can adequately describe the pyrolysis and combustion process of wood. We determine the rates of heat release, mass loss, and production of gases for selected wood species using an Ohio State Heat Release Rate Chamber. Empirical equations are being developed for heat release rate as functions of heat flux, density, moisture content, and time. Also, recent data quantify smoke production rates under non-flaming conditions. We obtained empirical equations that describe the smoke generation properties of particulate concentration and optical density of red oak and Douglas-fir plywood as functions of heat flux and time (Tran, in press).

Our research program in fire growth modeling is aimed at four objectives:

1. Assessing the various fire growth models that have been developed.
2. Developing subroutines specific to wood products.
3. Developing a data base of fundamental properties which can be input into fire growth models. These fundamental properties include thermal conductivity, specific heat, heat of combustion of the volatiles, etc.
4. Verifying fire growth models for wood products with full-scale room burn tests.

Using these fire growth models, we will gain valuable information concerning which parameters are the most important and how we can improve the fire performance of wood.

Fire Endurance

Work has been underway at the FPL to define the fire performance of conventional light-frame construction. Wall and floor performance has received special attention in the past (Schaffer and others 1983). Currently, efforts are concentrated on trusses and other fabricated wood products on the market. The basis for design of assemblies is to contain a fire within the room of origin. To do so the wall or floor assembly must act as a barrier to the fire. Typical assemblies are exposed to a standard fire test, ASTM E 119 (American Society for Testing and Materials 1985a), and the time is observed at which certain criteria are reached. The criteria include structural failure and the temperature rise on the unexposed surface.

Several years ago, the only way available to gain code acceptance of an assembly was to conduct a fire test by certified agencies. However, code authorities have increasingly accepted engineering analyses of fire performance. We, in the fire research unit, concentrated our efforts on developing models and design procedures for determining the fire endurance ratings of wood members and assemblies (Schaffer 1984).

In future research, we envision the fire growth models to define the exposure to an assembly, the heat transfer models to describe the flow of heat through the membrane and into the assembly, and the structural response models to calculate times to structural failure. All three make up a fire endurance model. The fire growth models have been previously discussed. The discussion will dwell now on structural response and heat transfer modeling.

The structural response of a wood member or assembly during a fire depends on the performance of its protective membranes, if any, the charring of the structural wood element, and the structural capacity of the remaining uncharred portions of the structural wood elements. FPL research has demonstrated that the fire endurance of a wood member can be calculated if it is assumed that (1) the strength properties in the entire uncharred region are a fraction of their room temperature value due to the temperature gradient within the member, (2) the charring rate is constant, and (3) the member fails when it is no longer capable of supporting its load which is some fraction of the ultimate load. Using these assumptions and the corresponding structural analysis models for the various members and assemblies, fire endurance formulas have been developed for unprotected joist floors (White and others 1984; Woeste and Schaffer 1981), glued-laminated beams (Bender and others 1985; Schaffer and others 1986), and unprotected floor trusses (Schaffer and Woeste 1981). Presently, we are developing such analytical procedures for walls and protected parallel cord and roof trusses. As part of our efforts on fire endurance of trusses, we have obtained new equipment that allows us to load a wood member in tension and simultaneously subject it to high temperatures or a direct fire exposure.

To calculate the residual mass of a wood member, we need to know the rate at which the wood undergoes thermal degradation. Currently our charring rates are based on fire exposures defined by a standard time-temperature curve (ASTM E 119 test method) (Schaffer 1967; White and Schaffer 1981). A theoretical charring model has been developed by Parker (1985) at the National Bureau of Standards. The model calculates the rate at which heat is released from the wood and the depth of the char layer using fundamental properties as input.

We need to know the rate at which heat is transmitted through a protective membrane such as gypsum wallboard. We are working cooperatively with Forintek Corp., Canada, on a heat transfer model for structural assemblies. We also worked with the University of California to develop a heat transfer model for light-frame wall assemblies. The finite element model can be used to simulate the ASTM E 119 fire test of a wall assembly (Gammon 1987). This allows us to determine the fire exposure of the assembly.

Also for certain applications, such as rehabilitation of a building, there is a need to improve the fire endurance of wood members. The steel industry improves the fire endurance of steel members with specially formulated fire-resistive coatings. These coatings are not designed for wood. However, we conducted evaluations of the steel coatings applied to wood and found that they could improve the fire endurance time of wood members. We developed empirical equations to determine the coating thickness needed to obtain a certain fire endurance rating (White 1984, 1986). Discussions are being held with chemical coating manufacturers and the wood industry to evaluate the commercial potential of such coatings for wood.

Fire Retardants

Fire retardant treatments (FRT) are frequently used to reduce the flammability of wood products. FRT can be pressure impregnated into the wood or they can be applied as a coating. Chemical impregnation has the greater use, primarily for new materials. Commercial testing agencies evaluate the effectiveness of the fire retardant systems using the 25-foot tunnel test, ASTM E 84-84a (American Society for Testing and Materials 1985b). Both coating and impregnation systems are based on the same chemical components, although the formulations for each vary. Most of the chemicals used in flame retardant formulations for interior finishing are based on empirical investigations for best overall performance. These chemicals include the phosphates, some nitrogen compounds, borates, and amino-resin systems. These compounds reduce the flamespread rating but can have adverse effects on other wood properties. The level of reduction on flamespread ratings depends on the total loading level of the chemical (LeVan 1984).

Most of the fire retardant treated lumber uses interior type chemicals that may leach out when exposed to outside weathering conditions. The need for exterior treatments resulted in a concentrated effort by many researchers in both government and industry, including the FPL. The research concentrated on exterior treatments for wood shakes and shingles. Today exterior fire retardant treatments exist for western redcedar shakes and shingles which qualify them for a Class C shingle or a Class B (ASTM E 108-83) (American Society for Testing and Materials 1985c) roof system. These treatments have been evaluated for durability under outdoor weathering conditions for 10 years (LeVan and Holmes 1986). Of all the treatments evaluated, the commercial treatment performed best in fire tests after 10 years of outdoor weathering. Some of the othe formulations, which we made at FPL, performed well in the Class C burning-brand test but showed increased flamespread in the modified Schlyter te Coating systems did not demonstrate long-term durability. Coating systems do not prevent the natural weathering of wood and are lost as a resu of defiberization of the surface wood cells by ultraviolet light.

Research, in progress, is concentrating on developing combined preservative and fire retarda treatments for several western whitewood species. To achieve this we are evaluating the fire performance of several preservative treatments and are conducting compatibility tests of various fire retardants and preservatives. We are examining single-step treatment processes and two-step treatment processes. The information gained from this study would be applicable to oth species. Such dual systems will greatly enhance the commercial applications of exterior wood products.

In other fire retardant research at the FPL, we a examining the mechanism of strength degradation d to FRT and high temperatures (Winandy and others 1987), the efficacy of FRT for structural corruga material and other composite products, and the fundamental fire properties of fire retardant treated wood.

APPLICATIONS TO THE WILDLAND/URBAN PROBLEM

Based on previous conferences, such as this, on t wildland/urban initiative, one research element that has routinely been expressed is the need for fire risk analysis models. These models take int consideration the past historical probabilities o fire, the current topography, the forest fire haz models, the building fire hazard models, the available suppression techniques, etc. The data base generated at FPL will provide information fo these fire risk analysis models to help describe the response of the building under various wildfi scenarios. New design procedures could be developed to mitigate the fire hazard and allow cost optimization. These design procedures could be incorporated into design manuals specifically for wildland/urban interface areas. They would present alternative construction systems and materials and provide greater flexibility to architects and builders.

However, caution must be exercised in using fire risk analyses models. The models are intricate, complex simulations and are only as good as the data on which they are built. Therefore, it is necessary that reliable and consistent informatio be used, which accurately describes the probable scenario. Cooperative effort will be needed amon all agencies to ensure that the data base is appropriate. Discussions should start addressing what information and format are needed. Such discussions will facilitate the utilization of these fire risk analyses models in the future by ensuring a sound and reliable data base.

CONCLUSIONS

This paper encapsulates the research work on fire being carried out at the Forest Products Laboratory. These areas include fire growth modeling of fires in compartments, fire endurance analytical procedures to describe the capabilities of structures during fire, and the effectiveness of fire retardant treatments to alter the flammability of wood products. This research will provide a source of information to help describe the response of wood building products to a wildland fire scenario and can be used in fire risk analyses models. Also, the FPL can help develop new design practices that can mitigate the fire hazard in these areas.

REFERENCES

American Society for Testing and Materials. 1985a. Standard methods of fire tests of building construction and materials. Desig. E 119-83. Philadelphia, PA: 349-375.

American Society for Testing and Materials. 1985b. Standard test method for surface burning characteristics of building materials. Desig. E 84-84a. Philadelphia, PA. 315-332 p.

American Society for Testing and Materials. 1985c. Standard methods of fire tests of roof coverings. Desig. E 108-83. Philadelphia, PA. 333-348.

Bender, D. A.; Woeste, F. E.; Schaffer, E. L.; Marx, C. M. 1985. Reliability formulation for the strength and fire endurance of glued-laminated beams. Res. Pap. FPL 460. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 43 p.

Bukowski, R. W. 1986. Introduction to fire hazard modeling. NBSIR 86-3349. Gaithersburg, MD: National Bureau of Standards. 93 p.

Gammon, Barry Wayne. 1987. Reliability analysis of wood-frame wall assemblies exposed to fire. Berkeley, CA: University of California. 377 p. Dissertation.

Jones, W. W. 1984. Model for the transport of fire, smoke, and toxic gases (FAST). NBSIR 84-2934. Gaithersburg, MD: National Bureau of Standards. 95 p.

LeVan, S. L. 1984. Chemistry of fire retardancy. In: Rowell, Roger M., ed. The chemistry of solid wood. Advances in chemistry series 207, chapter 14. Washington, DC: American Chemical Society.

LeVan, S. L.; Holmes, C. A. 1986. Effectiveness of fire-retardant treatments for shingles after 10 years of outdoor weathering. Res. Pap. FPL 474. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15 p.

Mitler, H. E. 1985. Harvard fire model. Fire Safety Journal. 9(1): 7-16.

Parker, William. 1985. Development of a model for the heat release rate of wood--a status report. NSBIR 85-3163. Gaithersburg, MD: National Bureau of Standards. 96 p.

Sauer, J. M.; Smith, E. E. 1983. Mathematical model of a ventilation controlled compartment fire. Journal of Fire Sciences. 1(7/8): 235-254.

Schaffer, E. L. 1967. Charring rate of selected woods--transverse to grain. Res. Pap. FPL 69. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 21 p.

Schaffer, E. L. 1984. Structural fire design: Wood. Res. Pap. FPL 450. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Schaffer, E. L.; Marx, C. M.; Bender, D. A.; Woeste, F. E. 1986. Strength validation and fire endurance of glued-laminated beams. Res. Pap. FPL 467. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

Schaffer, E. L.; White, R. H.; Brenden, J. J. 1983. Wall and floor systems: design and performance of light-frame structures. FPRS No. E16449. Madison, WI: Forest Products Research Society: 124-134.

Schaffer, E. L.; Woeste, F. E. 1981. Reliability analysis of a fire-exposed unprotected floor truss. In: Metal plate wood truss conference. FPRS No. E13331. Madison, WI: Forest Products Research Society: 131-137.

Spelter, Henry; Maeglin, Robert; LeVan, Susan. 1987. Status of wood products use in nonresidential construction. Forest Products Journal. 37(1): 7-12.

Tran, Hao. (in press.) Quantification of smoke in the NBS smoke chamber--An empirical model for smoke generation properties of wood. Submitted to Journal of Fire Sciences.

White, R. H. 1984. Use of coatings to improve fire resistance of wood. In: Lieff, Morris; Stumpf, F. M., eds. Fire-resistive coatings: The need for standards. ASTM STP 826. Philadelphia, PA: American Society for Testing and Materials: 24-39.

White, R. H. 1986. An empirical model for predicting performance of fire-resistive coatings in wood construction. ASTM Journal of Testing and Evaluation. 14(2): 97-108.

White, R. H.; Schaffer, E. L. 1981. Transient moisture gradient in fire-exposed wood slab. Wood and Fiber. 13(1): 17-38.

White, Robert H.; Schaffer, E. L.; Woeste, F. E. 1984. Replicate fire endurance tests of an unprotected wood joist floor assembly. Wood Fiber Science. 16(3): 374-390.

Winandy, J. E.; LeVan, S. L.; Schaffer, E. L.; Lee, P. W. 1987. Effect of fire retardant treatment and redrying on the mechanical properties of Douglas-fir and aspen plywood. Res. Pap. FPL 485. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15 p.

Woeste, Frank E.; Schaffer, E. L. 1981. Reliability analysis of fire-exposed light-frame wood floor assemblies. Res. Pap. FPL 386. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15 p.

A PRIMER ON FIRE ECOLOGY, FIRE BEHAVIOR, AND FUEL MANAGEMENT FOR THE WILDLAND RESIDENT

Ronald H. Wakimoto, Panel Moderator

As I look back over the years and reflect on the wildfire problem along the urban fringe, I think about my first organized encounter with the topic. In 1971, as a graduate student at Berkeley, I attended a meeting of the Governor's Task Force on California's Wildland Fire Problem. For the most part, the topics discussed at that meeting were the same as we have discussed here--building clearance enforcement, inadequate access, interagency coordination needs, improved construction codes, lack of zoning restrictions, etc. The big difference I see between then and now is our openness about not being able to protect every home and our emphasis on the need for homeowners to accept the responsibility for fire safety.

This panel program was designed as a homeowner's primer to fire ecology, fuels and fire behavior, and fuel management. It is our belief that to motivate a homeowner into action, he or she must realize that fire has always been a common occurrence in the vegetation of the Interior West--the vicinity of today's wildland homes--and that this must be considered in home design, placement, and landscape design.

As plants grow, they shed leaves, twigs, and branches. Over time shrubs and trees die out and are added to these other fuels. The limited rainfall in the Interior West allows fuels to build up since the rate of fuel accumulation is greater than the rate of decomposition. In the past, lightning-caused fires and those ignited by native peoples, reduced this fuel buildup over large areas. In addition, these fires favored plant species adapted to recurrent fires. The extermination of native cultures and effective fire suppression have allowed fuels to build up for over 100 years!

Once a homeowner accepts the fact that a damaging wildfire is likely to occur, he or she must also have a feeling for the expected fire behavior so that home design, home placement, and landscaping design can be cost-effective, and socially acceptable. When I say fire behavior, I mean the rate of fire spread, the length of the flames, and the likelihood of fire spreading into the crowns of trees or by burning embers flying long distances through the air in front of the fire.

An understanding of the potential fire behavior should help answer many homeowner questions. What fire behavior can be expected in the different vegetation types in the Interior West? Should homesite planning favor long flames with greater radiated heat or lesser flames with a rapid rate of spread? What roof coverings are acceptable? How wide a clearing is necessary to help protect a home? Will window shutters help? How about sprinklers on the roof? Should one fight or flee when the fire comes?

Finally, the homeowner must understand the importance of fuel management. Homes with properly managed fuels may be selectively defended by limited fire suppression forces while other homes will be allowed to burn. How much fuel is too much? Should these trees by cut or limbed up? How long will the fuel management effort last? Unfortunately, in many cases, the threatening fuel hazards lie outside the homeowners property boundary. Only informed homeowners, working with government agencies, can bring about a socially acceptable political solution to manage these hazards.

I hope that the panel presentation will increase homeowner understanding of the growing fire problem and their role in its solution in the Interior West.

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onald H. Wakimoto is an associate professor, niversity of Montana School of Forestry, issoula, MT.

FIRE ECOLOGY OF VEGETATION COMMON TO WILDLAND HOMESITES

Stephen F. Arno and Ronald H. Wakimoto

ABSTRACT: A synopsis of fire history and implications for fire management is presented for six major vegetation types of the interior West that contain large numbers of homes. For thousands of years prior to 1900, these vegetation types burned periodically. During the current century, however, fire has been suppressed and fuels have been accumulating, increasing the hazard of uncontrollable fire. Homeowners can greatly reduce the threat of severe fire damage by thinning and otherwise managing their wildland surroundings.

Suburban homeowners are well aware that cultivated vegetation such as lawns, gardens, and shade trees grows continually. They recognize that this vegetation requires trimming or cropping to prevent it from becoming rank and unacceptable. One reason that suburbanites move to wildland settings may be to escape the drudgery of such cultivation.

We have some good news and some bad news for the hundreds of thousands of new homeowners in wildland settings of the inland West. The good news is that they can indeed reduce the time spent cultivating vegetation. The bad news, however, is that wildland vegetation also accumulates and requires cropping to prevent it from fueling a home-destroying wildfire.

Wildland vegetation can be thought of as a natural fuel that has, since time immemorial, been cropped and regenerated by fires. When protected from fire, grazing, and wood harvesting, vegetation can develop into a dangerous fuel that sustains severe, uncontrollable fires. However, this vegetation can be cropped in such a manner that it becomes more aesthetically attractive while greatly reducing the risk of severe fire damage.

Modern Americans are accustomed to living in a cultivated landscape of cities, suburbs, and farms, where fire is generally considered an intruder. In recent years, multitudes have emigrated from that familiar setting and have built new homes in the wildlands, where fire is an important part of the natural scheme. In the interior West, the major vegetation types harboring wildland homes include semi-arid grasslands, sagebrush, dwarf-conifer woodlands, and various kinds of coniferous forests. Each of these types evolved under a characteristic pattern of fire frequency and fire severity known as a "fire regime." With limited exceptions, fire was an important natural disturbance in all these vegetation types.

Fire has had a major influence on vegetation in the shrublands, dwarf-conifer woodlands, and lower-elevation forests where large numbers of wildland residents have recently settled. A larg body of evidence concerning fire history in the interior West has been gathered through the study of fire scars on ancient trees and stumps, charcoal sediments in ponds, and accounts of earl travelers. Comparisons of hundreds of historical and modern photographs (retakes) of the Western landscape show a dramatic increase in density of shrubland, woodland, and lower-elevation forests. Also, this shrub and tree growth has expanded int former grasslands. Our knowledge of the response of different plants to fire confirms the authenticity of this trend.

The evidence shows that prior to the late 1800's, frequent fires swept through the grasslands and dry-site woodlands of the interior West. The tim period between fires at a given point on the ground ranged from only a year or two in the ponderosa pine forests of northern Arizona (Dieterich 1980) to a few decades in some of the mountain grasslands (Arno and Gruell 1983). Mois lowland forests in northern Idaho experienced fi on the average of once in a century (Arno and Davis 1980). Lower and middle elevations of the inland West were dominated by species that were best adapted to survival and regeneration in a fire environment (Habeck and Mutch 1973; Wright and Bailey 1982).

Patterns of frequent fires can be traced back thousands of years through charcoal layers in ponds (Mehringer 1985). Several factors were responsible. Abundant ignitions were caused by lightning and by Native Americans. The region's semi-arid climate provides dry periods favorable for burning, and prior to settlement by European-Americans, the landscape was a nearly continuous bed of fuels. Fires in forest and woodland types would often burn for a few months covering vast areas, until finally extinguished heavy rains or wet snows in autumn. Historic

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Stephen F. Arno is Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Ronald H. Wakimoto is Associate Professor, School of Forestry, University of Montana, Missoula, MT.

observations of fire are provided, for instance, by explorers Lewis and Clark, who encountered 10 wildfires in their travels through what is now Montana and Idaho in 1805 and 1806 (Gruell 1985).

Beginning in the mid-1800's, major changes affected fire frequency: (1) heavy livestock grazing and cultivation broke up the formerly continuous lowland fuels; (2) the nomadic lifestyle of Native Americans was abandoned, reducing ignitions; and (3) by the early 1900's organized fire suppression had become well established throughout the West. As a result of these changes, the amount of fire in grassland and dry forest types decreased dramatically. For instance, fire history studies show that most ponderosa pine stands that experienced fires at 5-10 year intervals prior to 1900, have recorded only 0-2 fires since 1900 (Martin 1982; Stokes and Dieterich 1980).

With this general scarcity of fire, shrubs and trees have expanded into former grasslands and have thickened in formerly open woodlands. Grazing has been reduced or eliminated in many wildland residential areas, resulting in buildups of dry grass and other fine fuels that allow fires to spread rapidly. The general trend is a thickening of vegetation that contains large amounts of dead, highly-combustible material. This trend varies by vegetation type; consequently we will describe specific conditions associated with some of the major types that harbor wildland residential development in the interior West.

PRAIRIE GRASSLANDS

Prairie grasslands cover vast areas of the western Great Plains and smaller areas west of the Rocky Mountains. Collectively these grasslands represent millions of acres of continuous fine fuels. Since time immemorial, grasslands experienced frequent fires started by lightning and Native peoples (Eiseley 1954). The combination of a semi-arid climate and abundant fine fuels makes the occurrence of fire almost inevitable. Early travelers and residents of the prairies often battled fires, with great losses of livestock, forage, fences, homes, and entire towns (Jackson 1965). Dry grass fuels were available during much of the year, and a single fire might spread to massive size before being checked by rainfall, a previously burned site, or a broad river.

Although major portions of the prairie grassland have been converted to cropland and crisscrossed by roads, the annual buildup of fine fuels ontinues on much of the landscape. This creates a potential for enormous fast-moving wildfires. Many homes in this setting are isolated buildings with cured grass extending right up to the xterior walls. Concentrations of modern ranchettes" encircle many prairie towns and agnify the problem of protecting structures and people from wildfires.

The good news is that most grassland fires are relatively easy to suppress because the quantities of fuel per acre are low and fuels burn out quickly. Direct flame contact is usually required to ignite structures, and fire spread by airborne embers from the flaming front is limited. Hence, hand clearing of grass fuels from around buildings or establishment of watered lawns can provide protection from wildfires in most grassland situations. Livestock grazing can greatly reduce the amount of fine fuel, lessening the severity of burning and slowing the rate of fire spread. Additionally, road systems can be used as fire breaks.

The bad news is that fuel clearance around homes must be done every year. Despite the modest quantities of fuel, grass fires driven by strong winds can be dangerous and fast-spreading. As the density of home development increases, fuel reduction by grazing tends to be reduced or excluded. The vastness of the prairie lengthens response times for firefighters. Much of the land is protected by volunteer firemen who must drive from long distances to man the fire trucks. In many cases the rapid growth of a grassland fire taxes the limited suppression forces and prevents protection of numerous scattered homes.

Central Montana's Hawk Creek Fire of 1984, spread primarily through grass fuels and then burned at high severity in accompanying groves of ponderosa pine. This fire's rapid growth illustrates the difficulty of containing a grassland fire. In 3 days it covered 24,000 acres. Then, strong winds pushed the inferno nearly 10 miles in 2 hours along a flaming front 3 miles wide! The fire front was so broad that suppression was impossible until weather conditions moderated.

SAGEBRUSH-GRASS

The sagebrush-grass vegetation type covers about 100 million acres of the interior West, mostly in the valleys and lower mountain slopes. These shrublands have become popular building sites for "country living." Perhaps because this land is less expensive than woodland, development tends to be dispersed over large areas; this makes it difficult to defend homes from a wildfire.

Studies of fire history and vegetation change indicate that prior to settlement much of the current sagebrush-grass type was a fire-maintained grassland that burned at intervals of perhaps 20 to 30 years (Arno and Gruell 1983; Houston 1973). Many of the drier or rockier sites were historically sagebrush and burned at longer intervals--30 to 70 years (Gruell 1986; Harniss and Murray 1973; Wright and others 1979). Most species and varieties of sagebrush are killed by fire. Thus, these shrubs were less abundant in the past when fires were more frequent. Livestock grazing on these lands since the 1800's has led to sagebrush dominance over large areas with native perennial grasses virtually eliminated. Introduced weedy species such as cheatgrass often provide abundant fine fuels.

The good news is that sagebrush is a non-sprouting or weakly-sprouting shrub that can be easily thinned out or removed around home sites. Such clearing may be effective for 10 years or longer. Grazing limits accumulation of fine fuels in many areas, which hampers fire spread.

The bad news is that each year some severe, wind-driven fires develop in sagebrush-grass types. These spread rapidly and are uncontrollable until the weather moderates. Sagebrush-grass fires generate much higher intensities than grassland fires, leading to ignition of homes by radiation and spotting (fire spread by wind transport of burning embers) as well as by direct flame contact. The openness of sagebrush-grass landscapes allows strong winds and wind shifts to play havoc with fire suppression tactics.

In 1987 conflagrations raced across sagebrush-covered slopes on the outskirts of both Boise and Pocatello, ID, forcing hasty evacuations of dozens of homes. Luckily, winds moderated in time to prevent large losses. Only three homes were destroyed. During the same summer, the Acorn Fire on the east slope of the Sierra Nevada destroyed 24 homes and damaged six others. Burning under the influence of the "Washoe Zephyr," a strong hot-dry wind (foehn), this fire spread at over 6 miles per hour in sagebrush-bitterbrush-grass fuels. Spot fires repeatedly developed 1/4 mile ahead of the fire front. Fortunately, the Acorn Fire eventually spread up against an area that had previously burned in another severe fire, and the lack of fuels aided the control effort. Use of prescribed fire by professionals at strategic locations may be necessary to limit fire spread and avert home damage in the sagebrush-grass type.

DWARF CONIFER WOODLANDS

Dwarf conifer woodlands made up of various species of juniper, pinyon, or occasionally limber pine cover vast areas of the interior West. These expanses of dense, bushy conifers are popular for residential development because of the screening and privacy they afford in otherwise open, semi-arid country. Residential development in dwarf woodlands is common in central Oregon and along the eastern base of the Cascades and Sierra Nevada--for instance, near Reno. It also is abundant at Santa Fe and around many of the other higher-elevation cities and towns in the southwestern United States.

Evidence from historical photographs, original land-survey records, and vegetation studies indicates that the dwarf conifer woodlands have become more dense and have often expanded into former sagebrush-grass types during this century (Burkhardt and Tisdale 1976; Gruell 1986; Martin and others 1978; Rogers 1982; Wright and others 1979; Young and Evans 1981). This can generally be attributed to livestock grazing that removed grass fuels and thus prevented surface fires from spreading. Prior to the late 1800's, periodic fires helped maintain open or patchy stands in many areas that now support dense woodlands.

The good news for modern residents is that surface fires in these woodlands are often hampered by sparse fuels. The bad news is that under hot, dry, windy conditions, severe crown fires can develop. These create an inferno that defies control despite modern fire-suppression technology. This type of fire racing through continuous fuels will consume homes lying in its path. For example, in 1981 a fire in sagebrush and conifer woodland nearly overran the town of Austin, NV, including a National Forest ranger district headquarters. The fire started 2-1/2 miles from Austin, but, despite suppression efforts, covered 6,000 acres in 6 hours. The town was saved largely because of a last-minute shift in wind direction.

PONDEROSA PINE

Ponderosa pine forests (including the closely-related Jeffrey pine) are abundant in the Western United States. As a result of their accessibility, relatively mild climate, and aesthetic appeal, hundreds of thousands of homes now occupy these forests from the Black Hills of South Dakota to the mountains above Los Angeles, and from the sunny lake country of south-central British Columbia to the suburbs of Flagstaff, AZ, and Boulder, CO.

Because of its large, shielded buds and thickening layer of protective bark, ponderosa pine begins to develop resistance to surface fire at an early age; consequently it is well adapted to survival under a regime of frequent fires. Oldgrowth trees throughout the species' range often have charred wounds or "catfaces" that show scars inflicted by 10 to 30 individual fires. By dating these multiple fire scars, researchers have learned that prior to 1900 most stands burned at intervals ranging from 2 to 25 years (Martin 1982). Frequent surface fires thinned out the smaller trees and kept the stands open and park-like. This allowed little opportunity for fuel buildup and stand-destroying crown fires.

Since 1900, however, most of these forests have experienced few if any fires. Modern stands tend to have dense patches of understory trees and a buildup of pine-needle litter and woody fuels. When a wildfire occurs under warm, dry, windy conditions, it often develops into an uncontrollable crown fire that destroys the forest and any homes within it.

By contrast, in a few cases severe wildfires have spread into ponderosa pine stands where prescribed burning or other fuel reduction had been carried out (Biswell 1977; Biswell and others 1973; Cooper 1960; Wagle and Eakle 1979). In each case, when the wildfire reached the previously treated stand it stopped burning through the tree crowns and became a controllable surface fire.

The ponderosa pine zone has a semi-arid climate, and after a few days of dry weather, pine-needle litter burns readily. Therefore, spreading fire is possible during much of the year. As far as homeowners are concerned, the good news is that fuels management is very effective and can be carried out in a variety of ways. The bad news is that without fuels management the risk of severe fire damage is great and fires can threaten homes even during the seasons when fires are generally uncommon.

In August 1984 the Hawk Creek Fire burned 44 homes in a ponderosa pine forest north of Billings, MT. These were mostly newer homes in untreated pine stands with fuels adjoining the buildings. In an evaluation of the fire, suppression officials concluded that these structures could have been saved if fuels management had been initiated. In 1985, 19 homes were destroyed in north-central Washington by the Barker Mountain Fire as it spread across ponderosa pine-covered slopes. Protection efforts were hampered by the dispersion of homes in secluded locations and by poor access roads.

In 1987, the Hangman Fire burned two dozen homes in a pine woodland subdivision near Spokane. Land Commissioner Brian Boyle stated that there are probably thousands of developments in Washington similar to Hangman Hills that face similar risks (Spokane Spokesman-Review, 19 July 1987). Moreover, the district fire chief declared that people with secluded homes in the forest outside the subdivisions are at substantially greater risk.

The number of homes in hazardous fuel situations in the ponderosa pine type throughout the West has increased rapidly in recent years, and unless fuels management is begun in earnest it seems inevitable that large losses of forests, homes, and possibly lives will occur.

MIXED FIR

Mixed fir forests occupy moist zones in the high mountains throughout the interior West. They also occur at lower elevations in northern Idaho, northeastern Washington, northwestern Montana, and southeastern British Columbia. These forests are a diverse assemblage containing Douglas-fir, grand fir, or white fir in mixture with other conifers. Small towns, outlying residences, summer homes, and ski and summer resorts are abundant in these forests as far south as the White Mountains of Arizona and New Mexico.

These forests burned infrequently in the past, at average intervals ranging from 20 to 150 years (Arno 1980; Dieterich 1983; Martin 1982). Fir forests containing sizeable quantities of ponderosa pine represent the shortest of these intervals. Prior to 1900, mixed fir forests experienced a range of burning from light surface fires to stand-destroying conflagrations. In mountainous topography an individual fire often left a patchy mosaic of contrasting burn treatments. This in turn broke up the continuity of fuels available for subsequent fires.

Residential developments in these forests today are generally surrounded by dense vegetation, both in the tree layer and undergrowth, which becomes a fire hazard only during an infrequent, severe summer drought. Because of the infrequency of such a hazard, home and resort owners in mixed fir forests are likely to be less conscious of fire and preventive measures than their counterparts in drier vegetation types. When fire does occur in these fir forests under extreme burning conditions, the luxuriant vegetation suddenly becomes a copious fuel.

Several small settlements in mixed fir forests were burned in the Great Idaho Fire of 1910; the mining city of Wallace barely escaped being razed (Cohen and Miller 1978). Severe fires are still uncontrollable, as witnessed by the Sundance Fire of 1967 that raced toward Bonner's Ferry, ID, burning more than 50,000 acres in a 9-hour run (Anderson 1968). In 1977 the Pattee Canyon Fire in a mixed fir forest near Missoula, MT, blew up and rapidly destroyed 1,200 acres including five homes. Ironically, if the same fire had occurred a decade later, many more homes would have been consumed, since subdivision development was just beginning in 1977. In 1979 and again in 1984, fires threatened the suburbs of Bonner's Ferry, despite the town's location on a large river.

In recent years the quantity and value of developments placed within untreated fir forests has increased dramatically. The frequency of conflagration in these types is comparable to that of a severe flood in a floodplain setting and the property damage potential from the fire equals or exceeds that of the flood; however the damage from fire is preventable with fuels management.

LODGEPOLE PINE

Lodgepole pine forests occur on relatively cold dry sites in the mountains of the interior West. Major resort and summer home developments occur at many locations including Banff and Jasper in Alberta, the Yellowstone-Grand Teton region, and the Colorado Rockies. In most of these developed areas, lodgepole pine is a fire-dependent species that burned in stand-replacing fires, primarily caused by lightning, at intervals of 50 to 150 years (Arno 1980; Hawkes 1980; Tande 1979). In some of the lodgepole pine forests, moderate surface fires also occurred and probably influenced the frequency of severe fires.

Populations of the mountain pine beetle (a native bark beetle) periodically build up and kill most mature lodgepole pines (>80 years old) over vast acreages. These epidemics create massive quantities of fuels, which are very slow to decay and remain available to support a conflagration.

In most areas, the very existence of a lodgepole pine forest testifies to a history of repeated, often severe fires. Lodgepole pine is considered the premiere fire-adapted species of the mountain forests, a sort of "Phoenix tree." Without periodic fires it is usually out-competed and replaced by other less fire-adapted trees such as subalpine fir and spruce. Lodgepole, however, bears abundant crops of wind-borne seeds at an early age. Large numbers of its seeds are also stored in protective closed cones that survive fire. These cones open only as a result of fire's heat and their seed falls into the excellent ash seedbed. The new stand grows up densely stocked and may later be killed by beetles--increasing the probability of severe burning, which will again favor the establishment of lodgepole pine. When lodgepole pine stands become old they become quite flammable as a result of tree mortality and a buildup of understory trees.

Large uncontrollable wildfires occur somewhere in the lodgepole pine forests during most years. In 1984 a wind-driven fire threatened summer homes and resorts on the east boundary of Glacier National Park. In 1985 another lodgepole pine forest fire, this one in central Idaho, blew up unexpectedly and overran 73 Forest Service firefighters (Rothermel and Mutch 1986). Their lives were saved only because they carefully assembled in clearings and crawled inside special metallic fire-tents. Luckily this fire occurred in an undeveloped area. Similar heavy fuel loadings can be found in lodgepole pine forests near many mountain resorts and summer home areas.

For property owners in lodgepole pine forests the good news is that fuels management is relatively easy and quite effective. The bad news is that because of the infrequency of fire hazard and the short season of occupancy on most of these sites, it is tempting to postpone fuels management. Unlike firefighters, resorts and summer homes cannot be slipped into a metallic fire shelter at the last minute to survive a fast-moving wall of flames. Even if this could be done, the all-important green forest setting would still be obliterated and property values would plummet. With intensive management to thin the trees and reduce the surface fuels even the surrounding forest can be protected from wildfire.

In conclusion, it is essential that wildland homeowners recognize that they live in one of nature's "fire environments." The risk of wildfire is substantial and comes with their property. But homeowners can vastly reduce the potential damage from wildfire to their lives, homes, and wildland homesites. In contrast to the suburban homeowner who cultivates vegetation primarily to make it aesthetically pleasing, the wildland resident has an additional compelling reason to manage his vegetation--survival. Fortunately, the cropping of wildland vegetation can also enhance aesthetics and it can yield firewood or other useful products. The presentations that follow tell homeowners specifically how to reduce the wildfire threat in different wildland vegetation types.

REFERENCES

Anderson, H. E. 1968. Sundance Fire: an analysis of fire phenomena. Res. Pap. INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 37 p.

Arno, S. F. 1980. Forest fire history in the Northern Rockies. Journal of Forestry. 78: 460-465.

Arno, S. F.; Davis, D. H. 1980. Fire history of western redcedar/hemlock forests in northern Idaho. Gen. Tech. Rep. INT-81. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 21-26.

Arno, S. F.; Gruell, G. E. 1983. Fire history at the forest-grassland ecotone in southwestern Montana. Journal of Range Management. 36(3): 332-336.

Biswell, H. H. 1977. Prescribed fire as a management tool. In: Mooney, H. A.; Conrad, C. E., tech coords. Proceedings of the symposium on the environment; Consequences of fire and fuel management in Mediterranean ecosystems. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office 151-162.

Biswell, H. H.; Kallander, H.; Komarek, R.; Vogl, R.; Weaver, H. 1973. Ponderosa fire management. Misc. Publ. 2. Tallahassee, FL: Tall Timbers Research Station. 49 p.

Burkhardt, J. W.; Tisdale, E. W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 57: 472-484.

Cohen, S.; Miller, D. 1978. The big burn--the Northwest's forest fire of 1910. Missoula, MT: Pictorial Histories Publ. Co. 88 p.

Cooper, C. F. 1960. Changes in vegetation, structure and growth of Southwestern pine forests since white settlement. Ecological Monographs. 30: 129-164.

Dieterich, J. H. 1980. Chimney Spring forest fire history. Res. Pap. RM-220. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 8 p.

Dieterich, J. H. 1983. Fire history of southwestern mixed conifer: a case study. Forest Ecology and Management. 6: 13-31.

Eiseley, L. C. 1954. Man, the fire-maker. Scientific American. 191: 52-57.

Gruell, G. E. 1985. Fire on the early Western landscape: an annotated record of wildland fires 1776-1900. Northwest Science. 59: 97-107

Gruell, G. E. 1986. Post-1900 mule deer irruptions in the intermountain West: Principle cause and influences. Gen. Tech. Rep. INT-206. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 37 p.

Habeck, J. R.; Mutch, R. W. 1973. Fire-dependent forests in the northern Rocky Mountains. Quaternary Research. 3: 408-424.

Harniss, R. O. Murray, R. B. 1973. 30 years of vegetal change following burning of sagebrush-grass range. Journal of Range Management. 26: 322-325.

Hawkes, B. C. 1980. Fire history of Kananaskis Provincial Park--mean fire return intervals. In: Proceedings of the Fire History Workshop. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 42-45.

Houston, D. B. 1973. Wildfires in northern Yellowstone National Park. Ecology. 54: 1111-1117.

Jackson, A. S. 1965. Wildfires in the Great Plains grasslands. In: Proceedings, 4th Annual Tall Timbers Fire Ecology Conference. Tallahassee, FL: Tall Timbers Research Station: 241-259.

Lotan, J. E.; Brown, J. K; Neuenschwander, L. F. 1985. Role of fire in lodgepole pine forests. In: Proceedings of a symposium: Lodgepole pine--the species and its management. Pullman, WA: Washington State University, Forestry Extension Department: 133-152.

Martin, R. E. 1982. Fire history and its role in succession. In: Proceedings of a symposium: Forest succession and stand development research in the Northwest. Corvallis, OR: Oregon State University, Forest Research Laboratory: 92-99.

Martin, R. E.; Dealy, J. E.; Caraher, D. L. 1978. Proceedings of the western juniper ecology and management workshop. Gen. Tech Rep. PNW-74. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 177 p.

Mehringer, P. J., Jr. 1985. Late-Quaternary pollen records from the interior Pacific Northwest and northern Great Basin of the United States. In: Bryant, V. M., Jr.; Holloway, R. G. eds. Pollen records of late-Quaternary North American sediments. Dallas, TX: American Association of Palynologists: 167-189.

Rogers, G. F. 1982. Then and now--a photographic history of vegetation change in the central Great Basin desert. Salt Lake City, UT: University of Utah Press. 151 p.

Rothermel, R. C.; Mutch, R. W. 1986. Behavior of the life-threatening Butte Fire: August 27-29, 1985. Fire Management Notes. 47(2): 14-24.

Sher, J.; Witkowsky, K. 1987. Rural homes coexist with threat of fire. The Spokesman Review, Regional Section: C1. Spokane, WA, July 19.

Stokes, M. A.; Dieterich, J. H. 1980. Proceedings of the fire history workshop; 1980 October 20-24; Tucson, AZ. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 142 p.

Tande, G. F. 1979. Fire history and vegetation patterns of coniferous forests in Jasper National Park, Alberta. Canadian Journal of Botany. 57: 1912-1931.

Wagle, R. F.; Eakle, T. W. 1979. A controlled burn reduces the impact of a subsequent wildfire in a ponderosa pine vegetation type. Forest Science. 25: 123-129.

Wright, H. A.; Bailey, A. W. 1982. Fire ecology: United States and southern Canada. New York: John Wiley and Sons. 501 p.

Wright, H. A.; Neuenschwander, L. F.; Britton, C. M. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities--a state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Young, J. A.; Evans, R. A. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34: 501-506.

FUEL CHARACTERISTICS AND FIRE BEHAVIOR CONSIDERATIONS IN THE WILDLANDS

Hal E. Anderson and James K. Brown

ABSTRACT: Characteristics of forest fuels, how they are related to flammability, and the types of fires most hazardous to wildland homeowners are explained. Tables and figures are presented to increase those homeowners' awareness of wildfire potential and hazard. Dangers of firebrands are emphasized. Means for reducing available fuels and flammability levels are discussed.

INTRODUCTION

Wildland fires pose problems for suburban and rural homeowners as they try to protect their investments. In much of the western United States, the potential for fire problems develops in the spring, heightens in the summer, and can continue into the late fall. Firefighting agencies begin strengthening their resources in the spring and sustain them into the fall. Wildland dwellers need to develop the same readiness and be aware of how fuels and fire potential can endanger their lives and homes. In this paper we explain fundamental aspects of wildland fuels and fire behavior.

FUEL CHARACTERISTICS

Moisture content may be the most important single property controlling flammability of both live and dead fuels. It reflects weather and climate and can change rapidly. Moisture content is usually expressed as a percent of oven dry fuel weight. Live and dead fuels retain water in different ways and respond differently to changes in weather. The moisture content of dead fuels fluctuates with changes in relative humidity and fuel temperature. Rainfall, of course, also affects fuel moisture content. Thin particles, such as dead leaves and grass stems that are loosely arranged, can change moisture content considerably in only a few hours. In contrast, days and weeks of drying conditions are required for moisture content of dead limbwood and down logs to change significantly.

Moisture content of living vegetation changes primarily in response to seasonal growth stages. For example, moisture content of herbaceous plants typically ranges from 200 to 400 percent oven-dry weight (OD) early in the growing season. Depending on species, it gradually decreases to 100 to 200 percent OD by late summer. Then as plants, such as annuals, or parts of plants die, moisture content drops dramatically and responds thereafter as dead fuel moisture content. This process can be hastened by summer drought. Shrubs undergo a similar change, but as long as the stems and leaves are alive, moisture content usually remains at or above 80 to 100 percent OD. The significance of seasonal change in moisture content is that (1) some live vegetation becomes dead fuel, which has considerably lower moisture content; and (2) the moisture content of the remaining live vegetation is lowered, thus, less energy is required for ignition.

Fuel quantity influences whether or not a fire will spread and determines how hot it will burn. It is expressed as tons per acre or in similar units. For a surface fire to spread, there should be at least 1/2 ton per acre (Wright and others 1979) of dry, fine fuel dispersed over the area. Fire intensity is directly proportional to the quantity of fuel that burns. All vegetation is not necessarily fuel. The quantity of vegetation that is available to burn is called "available fuel" and depends on several other fuel properties particularly the proportion of vegetation that is dead, fuel particle size, moisture content, and continuity. Fuel quantity varies greatly across the landscape even within short distances. Clumps of fuel formed by patches of shrubs or young conifer trees intermixed with fallen tree boles, branches, and twigs often account for flare-ups and surges in fire intensity that cause crowning and spotting.

Flammability increases markedly as the quantity of finely divided dead fuel such as leaves, stems, and twigs increases. The size of fuel particles is important because it relates to rate of heating and moisture exchange. Thin fuel particles have large surface areas compared to volume. Thin particles will generally dry out and ignite quickly because the large proportion of surface area to volume permits rapid exchange of moisture and heat; larger fuel particles take longer to ignite. Since fire spread is really a series of ignitions, thin fuels support higher rates of spread than large fuels because they ignite faster.

Compactness refers to the spacing of fuel particles. It is often expressed as weight of fuel per unit volume of fuel bed. The best way to reduce flammability by altering compactness is to compact fine fuels and separate or spread large fuels. Combustion is maximum when fine fuels are loosely compacted. Thus the fuel particles are close enough to receive intense heat radiation

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Hal E. Anderson and James K. Brown are Research Physicist and Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

from adjoining burning particles but not so close as to restrict flow of oxygen to the burning fuel. The forest floor of ponderosa pine is more flammable than in fir and lodgepole pine forests because the long needles of ponderosa pine produce a fluffy, less compacted litter layer than the short needles of fir and lodgepole pine.

Continuity of fuel refers to the distribution of fuels both horizontally and vertically. Continuity partly controls where a fire can go and how fast it travels. Horizontal continuity can be thought of as a uniform or patchy distribution of fuel. Spread of surface fire and crown fire is interrupted in patchy fuels and can be more easily suppressed. When the crown canopy of conifers is less than 75 percent closed, crown fire potential is reduced substantially (Fahnestock 1970).

Ladder fuels, such as moss hanging in trees, needles draped on shrubs, and shrubs and small conifers growing beneath larger conifers increase flammability and likelihood of crown fire by creating vertically continuous fuels.

The properties of fuel vary considerably within and between vegetation types. Perhaps the most important difference is the length of time during the year that fuels and fire behavior potential remain hazardous, which largely reflects moisture content. Dry landscapes that support vegetation such as sagebrush, pinyon pine, juniper, and ponderosa pine have low dead-fuel-moisture contents much longer during the year than higher elevation conifer forests of fir and lodgepole pine. Usually, quantities of downed woody material are greater in the fir and lodgepole pine forests than in drier forests and dwarf woodlands. Also, tree crown canopies are more continuous in fir and lodgepole pine forests. Thus, when surface fuels are dry, high intensity crown fires are more apt to occur in these forests.

Fuels are Ever Changing

Fuel conditions change greatly across the landscape and they change with time on the same piece of ground. Some fuel characteristics, such as moisture content, can change rapidly while other characteristics change slowly over a period of years. The variations in fuel can cause pronounced changes in fire behavior. Homeowners, land development planners, and forest managers all need to recognize that fuels and fire behavior are dynamic phenomena. They are not fixed in time or place.

The moisture content of fine dead fuels can change in a few minutes due to rainfall. In the absence of precipitation, moisture content of dead fuels fluctuates with constantly changing temperature and relative humidity. Seasonal growth and curing of herbaceous vegetation result in production of lush live vegetation that dries into flammable fine fuel in only a few months.

Most fuel characteristics such as quantity, size, continuity, and the proportion of dead-to-live material change slowly over time. Quantities of available fuel, both dead and live, and continuity may increase or decrease over time as a result of two interacting processes (fig. 1) (Brown and See 1981). Fuels accumulate due to growth and mortality of vegetation, which creates available dead fuel. Countering accumulation is the depletion of fuels primarily due to decay, fire, or human physical removal. Growth of trees, which for some species increases the distance to their live crowns, can reduce available fuel by creating breaks in vertical continuity.

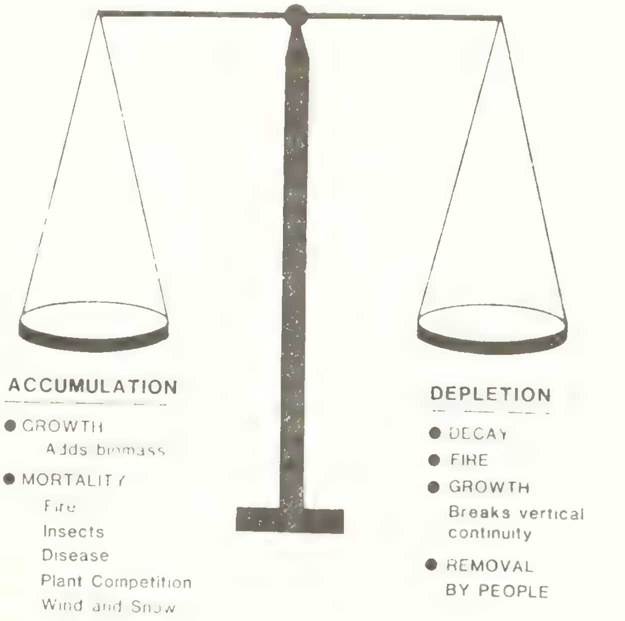

Figure 1--Fuels increase and decrease over time as a result of interacting processes.

Following a disturbance such as a severe fire or land clearing, the recovery of vegetation follows a similar pattern on many sites. First, herbaceous plants appear and dominate the site for a few years. Then shrubs appear and increase in quantity. Finally, trees dominate the site, and the quantity of shrubs and herbaceous vegetation is reduced by competition. This process may occur over a time period ranging from 50 to 100 or more years depending on the site and initial vegetation. Accumulation of live and dead fuels, as well as small and large fuels, can follow different patterns. Mortality to vegetation due to insects, disease, fire, wind and snow breakage, and plant competition occurs irregularly. Thus, creation of dead surface fuels is less predictable than the growth of live vegetation.

Consider how fuels change in different vegetation types. In sagebrush-grasslands, perennial grasses typically increase rapidly following fire and remain with high coverage for about 60 years. Sagebrush increases slowly, peaks in coverage after about 30 to 40 years, then decreases. Junipers increase markedly after about 40 years and dominate the site after 60 or more years (Frischknecht 1975). The likelihood of high intensity fire is greatest when sagebrush and perennial grasses are available to carry fire into the crowns of juniper. As trees get bigger and surface fuels are reduced, initiation of high intensity crown fires is more difficult (fig. 2).

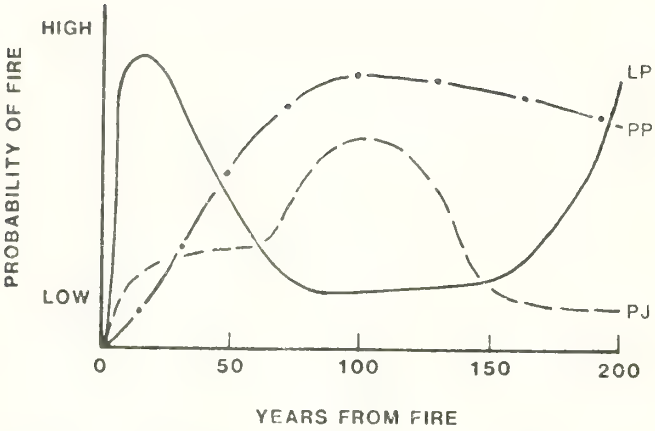

Figure 2--Hypothetical probabilities of high intensity wildfire due to changes in fuel over time since last stand replacement fire for lodgepole pine (LP) and ponderosa pine (PP) forests and pinyon-pine-juniper (PJ) woodlands.

In ponderosa pine forests, without repeated fires, surface fuels increase steadily over time largely due to the thickening of a conifer understory (Gruell and others 1982; van Wagtendonk 1985). The understory often serves as ladder fuels, which can readily ignite a crown fire. Ponderosa pine forests are most flammable after a conifer understory has developed and is maintaining good continuity with dead surface fuels. Today, many ponderosa pine forests in the western United States have developed high intensity fire potentials. Shrub and conifer understories have thickened due to absence of fire which historically thinned these stands.

The accumulation of fuels in fir and lodgepole pine forests is more complex because surface fuel flammability depends on fallen dead woody material. Generally, in overmature forests, potential fire intensity is high because of accumulated fuels (Brown and See 1981). In young to mature forests, fuel quantities and fire intensity potential vary greatly. However, one common pattern is a peak in fuel accumulation when forests are immature due to falldown of the previous stand that was killed by fire (Brown 1975). During the midlife of the forest, fire hazard is reduced as dead fuels decay and live tree crowns grow higher above the ground. When stands become overmature and decadent, dead fuels again accumulate, and the likelihood of high intensity fire increases (fig. 2).

FIRE PROPERTIES

Any time available fuel levels and adverse weather combine, wildfire potential is high. Homeowners should be aware of how those fires would most likely spread through their property. Fires are often categorized by the type of fuels that primarily support the combustion, namely ground fire, surface fire, and crown fire (fig. 3). Ground fires are primarily smoldering combustion of compacted wildland floor material and peat. They are of minor concern to homeowners. Surface fires spread along the surface of the ground in leaves, grasses, forbs, shrubs, and fallen woody twigs and branches. Crown fires spread through the crowns of trees by torching out trees as the surface fire ignites them or by spreading through tree crowns independently of the surface fire. Crown fires are usually pushed by strong winds or aided by steep slopes. Surface and crown fires are of major concern to homeowners because they can spread rapidly, burn intensely, and generate many airborne burning embers. These fires may cause houses to catch fire and burn by producing spot fires on flammable roofs, flame contact from burning shrubs or from a surface fire in ground litter, and burning embers that may reach the interior of houses through open windows, chimneys, vents, or under the eaves and patio decks.

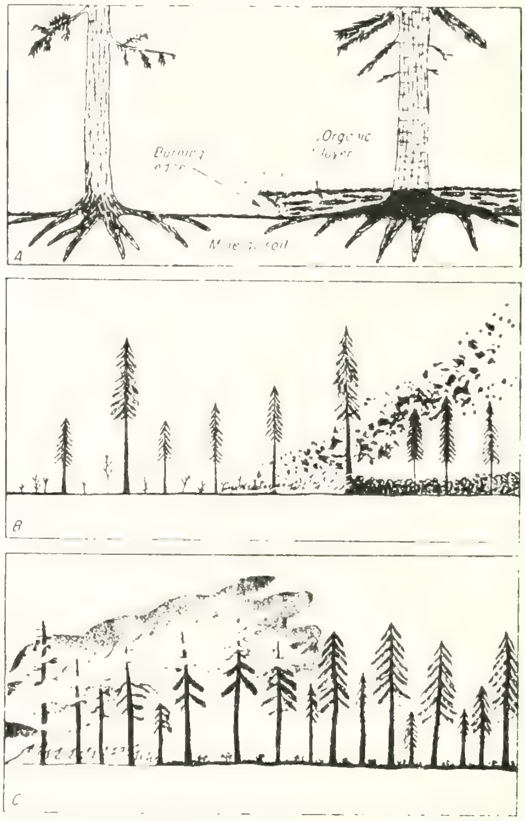

Figure 3--Wildfires are generally classified as A. ground fires, B. surface fires, or C. crown fires (after Brown and Davis 1973).

Fire intensity is the rate at which heat energy is released by combustion. Surface fires can range from low intensity, easy to control, to high intensity fires that are difficult to control. Crown fires are of high intensity and pose the greatest threat to homes. Despite modern firefighting technology, crown fires are almost impossible to stop until they run out of fuel or the wind stops. In a study of homes surviving bushfires in Australia, the lowest probabilities of surviving fire were associated with the highest fire intensities (Wilson and Ferguson 1986).

Flame length is an indicator of fire intensity and is considered to be the distance from the base of the flame to the tip of the flame (fig. 4). As the amount of fuel increases, especially the fine forest fuels, the flame length increases and can trigger additional problems.

The most serious features of wildfire besides rate of spread are:

A. Torching is the burning out of an individual tree or a group of trees. Generally, low limbs with foliage ignite and support burnout of the crown. Sometimes moss or lichens carry the fire to the interior of the tree crown where accumulated fine dead fuel is consumed.

B. Crowning is the extreme case of torching where weather, wind, and fuels combine to allow the fire to advance from tree to tree with rates of spread three to eight times faster than a surface fire (Rothermel 1983). Once the fire has developed into a "running crown fire," there is little that can be done to stop it. However, earlier fuel treatment can deny the fire sufficient fuel to continue crowning.

C. Spotting is caused by the lofting of burning embers (firebrands) in the flaming column and casting them downwind where they may land on ignitable material and start a new fire. Spotting sources can be a pile of woody debris, a torching tree, or a fire front moving across surface fuels or through the crown material of shrubs and trees.

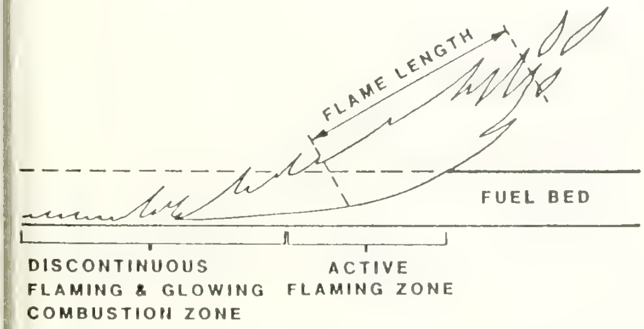

Figure 4--In the surface fire, flame length is the distance from the tip of the solid flame down to the midpoint of the active flaming zone (after Andrews 1986).

Wildfires spread primarily in fine forest fuels by a continuous series of ignitions. Rate of spread provides a measure of how fast a fire travels through the fuel. Because of the variety of conditions in which a wildfire can occur, the rate of spread can be from about 0.05 to 5 miles per hour.

For torching, crowning, and spotting to occur, there first must be an ignition; this is governed by the temperature and moisture content of fuel. When the fine fuels' moisture content is down to [illegible] percent OD and temperatures exceed 90 °F, the probability of ignition is equal to 50 percent or more. This means that one out of every two firebrands is capable of starting a fire if it lands in the proper fuel. If the moisture content drops to 4 percent and temperatures are above 90 °F, the ignition probability is 100 percent, a virtual certainty.

Fire Danger Index

It is important that woodland or forest dwellers be aware of the weather conditions that create fire danger to their homes and realize they will occur every year. There is available an indicator of how the fire danger is changing day by day in the National Fire Danger Rating System (NFDRS) (Deeming and others 1977). The expected burning intensity is estimated by considering the fuels, the season, and the weather and computing a Burning Index (BI) which is related to the expected fire intensity if fire occurs in the fuel type of a given area. This is most familiar on signs of Smokey Bear pointing to low, moderate, high, very high, or extreme fire danger. These levels of fire danger are related to the percent of the fire season days that are at a lower fire danger level, such as "very high" BI's are those that occur less than 10 percent of the time. "Extreme" BI's occur only 3 percent of the time or 97 percent of the BI's in a fire season are less than this value. Because climate, fuels, and current weather vary in each fuel type, the resulting BI's for each fire danger level may be different for each fuel type. Using sample areas for four common forest types in the interior West (sagebrush-grass, ponderosa pine, mixed fir, and lodgepole pine), the weather conditions at the midpoint of each manning level are shown in table 1.

Fire dangers that can threaten houses and other improvements in the wildlands are rapid spread rates, spotting, and crowning. Through these means, fire can be transported from a distant hillside to the homeowner's doorstep. Using the weather information gathered to assess fire danger, we have used the BEHAVE computer program to compute expected rate of spread, flame length, and fireline intensity (Andrews 1986) for various wildland types. The maximum fire behavior conditions that have occurred in the past 10 years are shown in figure 5 and table 2 to illustrate the full potential of wildland fire. The fire characteristics curve in figure 5 shows the results of applying fuel management practices in each forest and range fuel type examined.

SAFEGUARDING WILDLAND HOMES

There are several steps homeowners can take to reduce fire potential on their properties; reducing available fuel and decreasing flammability are discussed here. By reducing the amount of fine fuels, the rate of spread is sharply reduced. By reducing the quantity of fuel in all size classes, fire intensity and flame length are decreased so the fire can be directly attacked by ground firefighting resources. This is the objective of treating and modifying the fuels surrounding wildland homes; reduce and spread out the fuels so even fires occurring during extremely severe weather conditions are slow spreading and of low intensity. Forest dwellers may have very little time to avoid catastrophe if they wait for a fire before making preparations. It is important that all of the safeguards possible be accomplished prior to the ignition of a fire.

Table 1--Weather conditions--air temperature, relative humidity, and windspeed--are tabulated for midpoint BI's at each danger level for four NFDR zones in Idaho, Montana, and Wyoming. Each zone (polygon) has two or more NFDR weather stations reporting data over past 10 years

BI Levels	%	Air temp. °F	Rel. hum. %	Wind-speed mi/h
SAGEBRUSH-GRASSLAND				
Low	<22	71.5	43.0	4.5
Med	22-45	79.5	26.0	4.0
High	45-90	81.0	21.0	7.0
VHigh	90-97	82.0	18.0	12.0
Ext	>97	83.5	15.0	22.0
Max		93.0	5.0	43.0
PONDEROSA PINE FORESTS				
Low	<22	64.0	50.5	3.0
Med	22-45	72.5	34.0	4.0
High	45-90	78.0	27.5	5.5
VHigh	90-97	82.0	24.0	7.0
Ext	>97	85.5	20.5	8.5
Max		103.0	7.0	27.0
MIXED FIR FORESTS				
Low	<22	55.5	69.0	2.5
Med	22-45	65.0	51.0	3.0
High	45-90	71.5	42.0	5.5
VHigh	90-97	77.5	36.5	10.0
Ext	>97	79.5	30.5	12.5
Max		95.0	9.0	53.0
LODGEPOLE PINE FORESTS				
Low	<22	51.0	71.0	5.0
Med	22-45	65.0	46.0	5.0
High	45-90	68.5	35.5	8.5
VHigh	90-97	69.0	27.0	12.5
Ext	>97	65.5	25.5	17.5
Max		93.0	5.0	60.0

Because of limits on flame length, the likelihood of torching can be reduced by controlling how close the dead branchwood of trees is to the ground. If trees are pruned so that there are no branches less than 10 feet above the ground, even at "extreme" conditions there is little likelihood of torching. The maximum condition, though, would require pruning in excess of 13 feet. Pruning limbs to 18 feet above the ground will minimize torching and the generation of fire brands that cause spot fires.

Spot fires may, like a spreading fire, come to your house from a remote fire. Therefore, the homeowner must take precautions to minimize the chances for a spot fire to ignite. Spotting distances, once the windspeed is great enough to carry a firebrand, vary from less than 0.1 mile to 0.5 mile under "extreme" conditions, while the maximum distance may be more than 1 mile. When atmospheric conditions become very severe, large fires or conflagrations can occur and may develop large convection columns. Numerous firebrands can be lofted in these columns and carried by the winds several miles ahead of the fire front, as occurred in the Sundance Fire in northern Idaho

Table 2--Predicted fire characteristics for each forest type at the midpoint weather conditions cited in Table 1

BI Levels	Rate of spread mi/h	Flame length ft	Fireline intensity Btu/ft/s	Spotting distance miles
SAGEBRUSH-GRASSLAND				
Low	0.11	3.4	81	0.0
Medium	0.09	3.1	66	0.0
High	0.19	4.4	142	0.0
Very high	0.46	6.6	341	0.1
Extreme	1.33	10.7	985	0.3
Maximum	5.28	21.4	4442	0.8
Managed fuels	0.11	2.5	40	0.8
PONDEROSA PINE FOREST				
Low	0.04	2.1	29	0.1
Medium	0.06	2.5	42	0.1
High	0.10	3.1	68	0.1
Very high	0.13	3.5	87	0.1
Extreme	0.18	4.2	131	0.2
Maximum	1.26	10.8	999	0.5
Managed fuels	0.06	1.8	21	0.5
MIXED FIR FORESTS				
Low	0.01	1.2	9	0.0
Medium	0.01	1.9	23	0.0
High	0.02	2.6	46	0.1
Very high	0.05	3.5	86	0.1
Extreme	0.08	4.2	128	0.2
Maximum	0.56	11.4	1129	0.8
Managed fuels	0.09	2.0	25	0.8
LODGEPOLE PINE FOREST				
Low	0.01	0.9	4	0.1
Medium	0.03	2.3	35	0.1
High	0.04	3.2	71	0.1
Very high	0.08	4.1	120	0.2
Extreme	0.10	5.0	185	0.2
Maximum	0.73	13.1	1528	0.8
Managed fuels	0.10	2.3	34	0.8

in 1967 (Anderson 1968). Most woodland and forest dwellers have small acreages so the dimensions of their property lines are smaller than the spotting distances. The protection of their homes from spot fires and spreading fires depends on how well debris, woody residue, weeds, and grasses are cleaned up. This way, little fine fuel is available for ignition, reducing the fire potential.

Because firebrands account for the majority of burned homes, the owners must be aware of when their property would be easily ignited. An early warning is available by listening to the mid-day weather report for the temperature and humidity of the locality. The ease of igniting fine fuels like needles, dead grasses, dry cedar shakes or shingles, and old woody debris is dependent on the temperature and relative humidity. The ease of ignition or ignition probability is at its highest level when the temperature has reached its high and the relative humidity has reached its low. The critical time of the year to the wildland homeowner is when the ignition probability exceeds 50 percent. Because firebrands often occur as showers of thousands of embers, the homeowner may face an overwhelming task. Unless, of course, there has been an effort to fireproof the roof, remove flammable fine fuels in gutters, roof valleys, and under porches, and eliminate woody debris around the house. Estimates of ignition probability are shown in table 3 so the wildland homeowner can have some idea of the potential for ignition. Areas shaded by trees have lower probabilities of ignition than open sunny locations.

How can the characteristics of fuel be altered to reduce flammability? Removing fuel, particularly fine fuel, is certainly the most effective means of reducing flammability because it reduces fuel quantity and continuity. Planting less flammable species around homes can be helpful. Moisture content of live vegetation can be maintained at high levels by regular watering. Even lower rate of fire spread values can be achieved if ground litter is replaced by grasses or other moist ground covers. Establishing and maintaining green lawns, for example, can curtail spread of fire.

The effect of managing the fuels for each woodland type around woodland homes is illustrated in figure 5 and table 2. Note the values in table 2 below the maximum estimates; these values indicate the type of reduction in fire danger that can be expected with good fuel management.

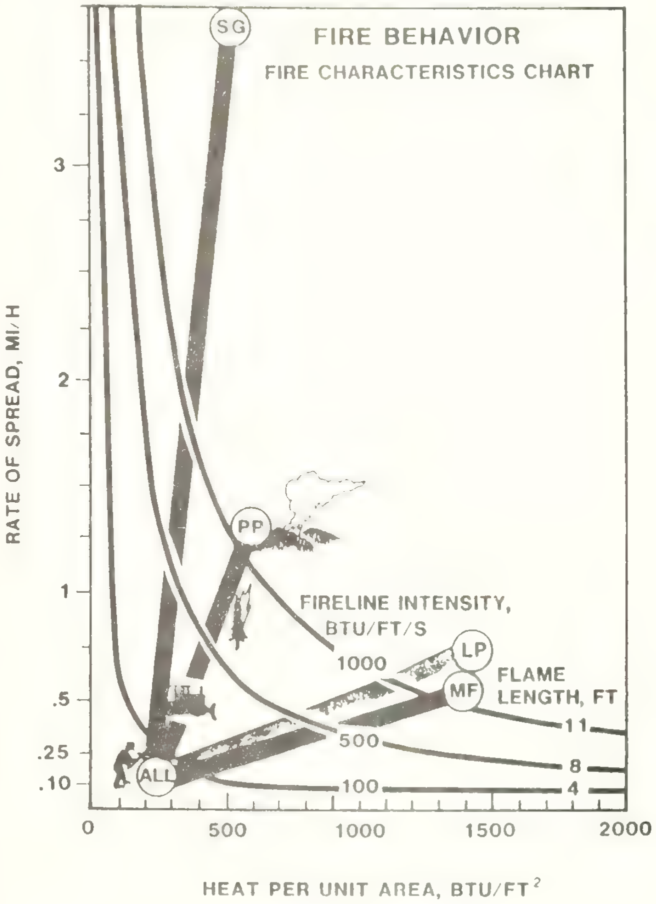

Figure 5--The fire characteristics chart shows how rate of spread and fire intensity change as fuels are modified: sagebrush-grass, SG; open ponderosa pine woodland, PP; mixed fir forest, MF; lodgepole pine forest, LP.

Table 3--Probability of ignition dependence on temperature, relative humidity, and shade

Air temp.	Relative humidity, percent													
°F	5		15		25		35		45		55		65	
	Probability of ignition, percent													
	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade
60	100	80	90	50	80	30	80	20	70	10	70	10	70	10
70	100	80	90	50	80	30	80	20	80	20	80	10	70	10
80	100	80	100	60	90	50	80	40	80	30	80	20	70	20
90	100	80	100	70	90	50	80	40	80	30	80	30	80	20
00	100	80	100	70	90	50	90	40	90	40	80	30	80	20
10	100	90	100	70	100	60	90	50	90	40	90	30	80	30
20	100	90	100	70	100	60	90	50	90	40	90	40	90	30

Fire prevention and control actions are often aimed at breaking continuity of fuel. Homeowners and forest managers have many opportunities for disrupting continuity by thinning, pruning, and creating fuel-free areas and by preventing continuous vegetation when planting and tending shrubs and trees.

REFERENCES

Anderson, Hal E. 1968. Sundance Fire: an analysis of fire phenomena. Res. Pap. INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 39 p.

Andrews, Patricia L. 1986. BEHAVE: fire behavior prediction and fuel modeling system--BURN subsystem, Part 1. Gen. Tech. Rep. INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 130 p.

Brown, Arthur A.; Davis, Kenneth P. 1973. Forest fire: control and use. New York: McGraw-Hill. 686 p.

Brown, James K. 1975. Fire cycles and community dynamics in lodgepole pine forests. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: Symposium proceedings; 1973 October 9-11, Pullman, WA. Pullman, WA: Washington State University Cooperative Extension Service: 429-456.

Brown, James K.; See, Thomas E. 1981. Downed dead woody fuel and biomass in the northern Rocky Mountains. Gen. Tech. Rep. INT-117. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. 1977. The National Fire-Danger Rating System--1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 63 p.

Fahnestock, George F. 1970. Two keys for appraising forest fire fuels. Res. Pap. PNW-99. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.

Frischknecht, Neil C. 1975. Native faunal relationships within the pinyon-juniper ecosystem. In: Proceedings of the pinyon-juniper ecosystem: a symposium. Logan, UT: Utah State University: 55-65.

Gruell, George E.; Schmidt, Wyman C.; Arno, Stephen F.; Reich, William J. 1982. Seventy years of vegetation change in a managed ponderos pine forest in western Montana--implications for resource management. Gen. Tech. Rep. INT-130. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 42 p.

Rothermel, Richard C. 1983. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 161 p.

van Wagtendonk, Jan W. 1985. Fire suppression effects on fuels and succession in short-fire-interval wilderness ecosystems. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C. Mutch, Robert W., technical coordinators. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 119-126.

Wilson, Andrew A. G.; Ferguson, Ian S. 1986. Predicting the probability of house survival during bushfires. Journal of Environmental Management. 23: 259-270.

Wright, Henry A.; Neuenschwander, Leon F.; Britton Carlton M. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities. A state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

CULTURAL PRACTICES THAT CAN REDUCE FIRE HAZARDS TO HOMES IN THE INTERIOR WEST

Wyman C. Schmidt and Ronald H. Wakimoto

ABSTRACT: Homes in natural grass-, shrub-, and forest lands are susceptible to wildfire. Cultural practices can be used to reduce fire hazard yet maintain a natural appearance. This paper discusses the most appropriate methods to use in each of four natural settings--grass, shrub, and dwarf conifers; ponderosa pine forests; mixed fir forests; and lodgepole pine forests. Complete fire-proofing is not possible but the probabilities of losing a home to wildfire can be substantially reduced with the relatively simple procedures discussed in this paper.

INTRODUCTION

Conifer forests and grass-shrublands have had a long association with fire in the interior West. Wildfires have shaped the character of most of the old-growth forests and grass-shrublands we have today; geologic history tells us that this has gone on for thousands of years (Lotan and others 1981). Most of our western coniferous forests are well adapted to fire because of characteristics such as closed cones that protect the seeds and thick bark that protects living tissue. In fact, most of our forests owe their very existence to fire because fire creates receptive seedbeds, reduces vegetative competition, and unlocks nutrients needed by many species to regenerate and grow successfully. Much the same can be said for the grass-shrublands because fire frequency determines which species will be successful in the long term. Unfortunately, wildfires are not compatible with the objectives of most people who have a home in these natural settings--they don't want their homes burned and they are satisfied with the natural setting around their home (Fischer and Books 1977; Guth 1987).

What can be done to help protect homes from wildfire in the interior West? There are many partial solutions to this problem including those that deal with the structure itself, access, firefighting capability, and the like. These are dealt with in other papers in this proceedings. This paper discusses how natural fuels contribute to fire hazard under various conditions and how these fuels can be modified to reduce the hazards. Included are cultural practices that modify the fuels on grass and shrublands and silviculture--the art and science of growing, tending, and modifying the forest.

Silviculture deals with two broad categories: tree establishment and culture of trees and stands that are already established. Because most people build in a particular vegetation type that already suits their lifestyle, establishment of new trees or other vegetation is seldom needed. Therefore we will focus our attention on cultural practices that modify existing vegetation to reduce fire hazard. These practices are normally used to adjust species composition, age distribution, stand density, and stand structure. The objectives are usually aimed at improving growth of trees, shrubs, and other vegetation, reducing insect and disease problems, and enhancing visual, wildlife, water, and other resource values. In this case however, the primary treatment objective is to reduce fire danger for homes while maintaining or enhancing esthetic values. Our intent is to discuss and illustrate some cultural practices that will enable homeowners to substantially reduce the risk of severe fire damage to their wildland homes (fig. 1).

VEGETATION TYPES

Four vegetation types are discussed in this paper--the grass-sagebrush-dwarf conifer woodlands found at the warm-dry end of the spectrum, ponderosa pine forests on the more moderate temperature and relatively dry climate areas, mixed conifer forests on the moist and relatively moderate temperature climates, and lodgepole pine forests on the cold-moist areas at the higher elevations. Many vegetation classification schemes are available for the interior West, but for simplification we are combining them into these four types where fire hazards are reasonably similar. All are

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Wyman C. Schmidt is Research Silviculturist and Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Bozeman, MT; Ronald H. Wakimoto is Associate Professor, School of Forestry, University of Montana, Missoula, MT.

Figure 1--Most people who want a "home in the woods" have in mind a particular setting and vegetative type that suits their lifestyle. Unfortunately, some of these idyllic settings are extremely vulnerable to life- and property-threatening fires. Fortunately, fire hazard can be reduced and this paper describes some of the methods.

commonly found throughout the interior West and are considered desirable home sites by many people seeking "pristine" environments.

Grass-Sagebrush-Dwarf Conifer

The open vistas of grasslands, sagebrush-grasslands, and dwarf conifer woodlands attract thousands of new homeowners every year. In the interior West this land is usually less expensive than acreage in conifer forests. Alternative land uses, other than livestock grazing, are limited. Considering the poor financial health of the livestock industry in recent years, many working ranches within a reasonable commuting distance from prairie cities and towns are being subdivided out of economic necessity. This often results in small acreage "ranchettes" that either exclude grazing or allow excessive animal use that can lead to the growth of unpalatable trees and shrubs.

In the interior West grasslands occur at lower elevations, generally below dwarf conifer woodlands and sagebrush-grasslands. Fine dead fuels are abundant and support fires that can develop high rates of spread. Environmental conditions allow dead grassland fuels to dry out quickly in the late winter or early spring. Prior to green-up, man-caused fires are common in most developed areas. In the late summer or fall perennial grasses die back to ground level providing continuous fine fuels over large areas. Summer drought simply speeds up the drying process. In fact, drought following 2 or 3 good growing years generally precedes major grassland fires (Lotan and others 1981).

Sagebrush-grasslands cover approximately 100 million acres in the West. Although historic fire frequency was lower in this type than in grasslands, sagebrush-grasslands combine the flammability of fine dead grass fuels with the foliage and heavier fuels of sagebrush to produce fast moving, high intensity fires. Wildfires have been observed spreading at nearly 6 mi per hour. Sagebrush density and coverage greatly affect rate of spread and intensity (Brown 1982). When shrub crown cover is less than 30 percent, 80 to 90 percent of the spread rate is determined by the quantity and continuity of grass fuels. In cases where shrub canopy cover is greater than 30 percent, rate of spread increases dramatically. Fire intensity, the heat produced per square foot, might be increased 100 times over that of the grass fire alone. It is interesting to note that historic grazing practices and fire suppression have increased the density of shrubs on the sagebrush-grasslands.

Dwarf conifer woodlands are best exemplified by the pinyon-juniper woodlands of the interior West. These woodlands are found at elevations below the ponderosa pine zone, but above the grasslands and sagebrush. Historically, fires every few decades apparently restricted the distribution and density of these dwarf conifers to shallow, rocky soils and rough topography. For the past 100 years heavy livestock grazing has reduced grass competition and fire occurrence, allowing pinyon and juniper to invade adjacent vegetation types. The rate of invasion and tree growth is usually slow with 30-year-old trees being barely 4 ft tall. Mature stands are open and park-like with very little fine fuel within the stand. Grass growth is chemically inhibited resulting in as much as 35 percent bare soil (Barney and Frischknecht 1974). Without fine dead fuels, such stands burn only under extreme temperature, humidity, and wind speed conditions.

Ponderosa Pine

Ponderosa pine forests are considered by many as prime home building locations. They produce large trees, often grow in open parklike conditions, have a unique forest fragrance, and because they are often open-grown provide a pleasant forest atmosphere without completely obstructing the view.

At the risk of oversimplification, ponderosa pine forests come in two categories. At the lower-drier end of the ponderosa pine type, ponderosa pine generally occurs in a wide range of tree sizes and is the only significant tree species; shrubs are sparse and grass is relatively abundant. Higher elevation and moisture conditions produce a somewhat different kind of ponderosa pine forest. Here, ponderosa pine is accompanied by those species that can tolerate more shade and require more moisture such as Douglas-fir, grand fir, or white fir. These associated fir species tend to occur in thickets with a wide range of tree sizes and live crowns extending to the ground. These layers of fir trees often serve as the ladder from the forest floor to tallest trees that can convert a slow-moving surface fire to a raging crown fire. Shrubs in this forest type are usually larger and more abundant than in the drier areas.

Fuels in this vegetation type are composed of easily ignited grasses and pine needles, some shrubs that burn readily (such as manzanita), downed branches and stems, small trees with flammable crowns extending nearly to the ground, and large trees with interlacing crowns. All of these add up to a serious fire hazard but one that can be reduced through the use of silviculture.

Mixed Conifer

Mixed conifer forests include a wide variety of associated conifers. In general, this forest type occurs at somewhat higher elevations, more moderate temperatures, and greater moisture than ponderosa pine forests. Douglas-fir, white fir, and grand fir occur in various combinations with several different pines, cedar, hemlock, western larch, spruce, and other species.

Dense multi-layered vegetation characterizes this zone, including tall overstory trees such as Douglas-fir, western larch, white pine, and others. They are usually accompanied by layers of understory trees of firs, spruces, hemlocks, and others plus a copious amount and variety of understory shrubs. Grasses occur, but they are not too important as a fuel because they are usually shaded out by dense tree and shrub overstories.

These combinations produce a lot of woody material. Fuels tend to accumulate in the form of down trees. Thick duff layers, consisting mainly of old conifer needles and twigs, tend to develop in this forest type. The moist conditions reduce the frequency of fire, but the accumulation of fuels and the ladder-like forest structure make fires very dangerous in the extremely dry periods when they do occur (Freedman and Fischer 1980).

Lodgepole Pine

Lodgepole pine forests are widespread throughout the interior West. They occur most commonly at relatively high elevations and are very desirable for summer home sites and homesites near winter recreation areas. The cooler temperatures and generally moister conditions result in a more homogenous forest with fewer tree and understory species than in the mixed conifer type. Lodgepole pine usually occurs in dense stands and dominates the overstory with only occasional subalpine fir and spruce as understory trees. As a result, the multiple layers so common in the mixed conifer forest are not usually a problem in these forests. Also, lodgepole pine self-prunes readily and, as a result, there is usually a significant gap in the fuel between the forest floor and live crowns. Shrubs, herbs, and grasses are very limited and do not make up much of the total available fuel.

The cool-moist conditions here often result in an accumulation of fuel in the form of down and dead lodgepole pine, particularly in older forests where shading in dense stands killed many of the smaller trees earlier and subsequently bark beetles killed many of the larger overstory trees. Duff layers are usually fairly thin.

FIRE HAZARD REDUCTION METHODS

When a large wildfire moves into a wildland residential area the only possible way to protect every home is to place a fire engine at each home. Management of wildland fuels to protect a home from wildfire is, for the most part, a do-it-yourself proposition and a homeowner's responsibility. Group actions, through homeowners' associations, are best applied to the dissemination of fire-safety information, to management of fuels in "common" areas, and to the enforcement or rewriting of covenants to improve fire safety. In the interior West fire suppression resources are limited. When fires occur suppression forces must pick and choose among homes of varying fire receptiveness, adjacent fuels, and access. Homes chosen will likely be ones that are defensible, of fire resistant design, with adequate fuel clearance, and have easy access. Home design and access are covered in other portions of this proceedings. Here we present fire hazard reduction methods that change the kind, amount, and arrangement of fuels adjacent to homes and yet maintain a pleasing home setting.

Grassland-Sagebrush-Dwarf Conifers

Because of substantial differences in the fuels found in this type, hazard reduction methods will be described for two categories of fuel--grass and shrubs-dwarf conifers.

Grass Fuels--Grass fires generally ignite homes through direct flame contact. Fuel management should concentrate on removing grassy fuels for 30 ft around all dwellings. Mowing and raking reduces the amount of fuel, the rate of fire spread and the fire intensity. Mowing should be done periodically starting in the spring. Do not wait until late summer to mow. Many fires are started accidentally by people mowing tall, dry grass during times of high fire danger. Watering the grass to keep it green in the summer gives added protection. Some rural homeowners intentionally burn these grass fuels in the spring. Unfortunately, their limited knowledge of fire weather and fire behavior sometimes gets them into trouble. As home density increases, so does the liability for an escape fire. Contact the agency with fire suppression responsibility for your area to discuss the equipment needs, burning techniques, and hazards before lighting grass fires.

Thoughtful landscaping around the structure is an excellent way to prevent direct flame contact. Concrete or gravel walkways around buildings can eliminate fuels next to the structure. Strategically placed rock gardens using native or crushed rock are effective, easily maintained barriers to fire spread. Riding trails, walking paths, and circle drives around the structure can be viewed as additional barriers to fire. Barrier widths should be three to five times the height of the uncut grass.

Shrubs and Dwarf Conifers--As the amount of fuel increases, so does the likelihood of a home igniting from radiation or spotting. Burning shrubs and dwarf conifers produce long flame lengths radiating great quantities of energy that can ignite drapes and other items inside a home, even before the exterior of the house is ignited. This high intensity also creates rapid upward air movement that can carry burning embers onto roofs and decks. Hence fuel management objectives are to increase the distance between these fuels and the dwelling and to reduce the likelihood of a number of shrubs and trees all igniting at one time.

Cutting and thinning shrubs and dwarf conifers and removal of dead fuels is the best way to reduce fire intensity in these vegetation types. Because most of these plants do not sprout vigorously after a fire, the effects of a major cutting and thinning effort will last 10 to 15 years or more. Individual plants should be spaced so that distance between plants is at least five times plant height. Dead branches should be pruned out and disposed of. Clumps of large shrubs or trees should be reduced to individual plants. This thinning should be done for at least 100 feet from buildings. The greatest vegetation reductions should be within 30 feet of the structures. This action also makes it easier to water and mow grass in that 30-foot area around the structure.

Conifer Forests

Fuels in conifer forests commonly form a ladder-like pattern that enhances the spread of fire from the forest floor into the crowns of the main canopy of the forest. These are commonly referred to as ladder fuels and as illustrated in figure 2, the analogy fits very well. The various fuels--needles, grasses, shrubs, woody debris, understory trees, and overstory trees--are analogous to the rungs in a ladder. Removal or alteration of any of these fuels takes one of the rungs out of the ladder and reduces the hazard of a severe crown fire.

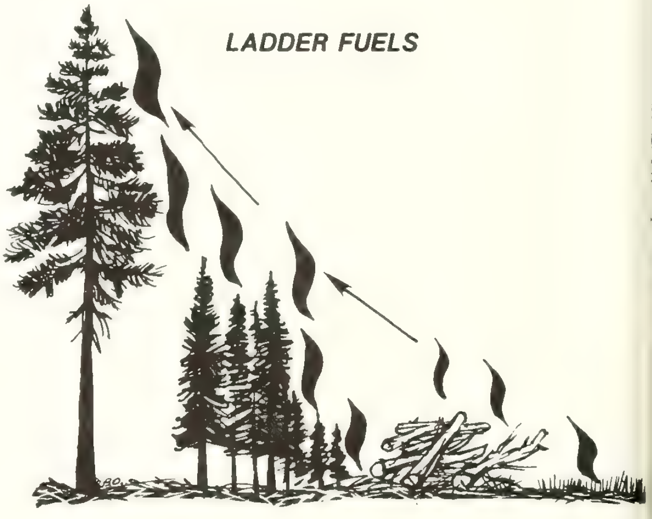


Figure 2--Fuels in this illustration form a ladder-like configuration that contributes to fire hazard. Removal of any of these fuels is similar to reducing rungs in a ladder--it makes it harder for fires to climb the fuel ladder.

Silvicultural practices can be used to reduce fire hazard by adjusting the amount and configuration of the three primary types of fuel that contribute to fire hazard: (1) live tree crowns, (2) dead organic material from standing or down tree stems, branches, needles, duff, and (3) other vegetation such as shrubs, herbs, and grasses. The same type of silvicultural practices are appropriate for each of the three forest types described earlier, but accomplishing the tasks will require different levels of effort in the different forest types.

Live Trees--Crowns of live trees are the primary source of fuel for a crown fire. Three things can be done to reduce this type of fuel: (1) thinning to separate tree crowns enough to reduce the probability of fire moving laterally from one crown to the other, (2) pruning to raise the lowest level of the crowns far enough from the ground to reduce the probability of a surface fire getting into the lower crowns of the trees, and (3) removing understory trees to reduce the probability of fire laddering from contiguous small to medium to large trees.

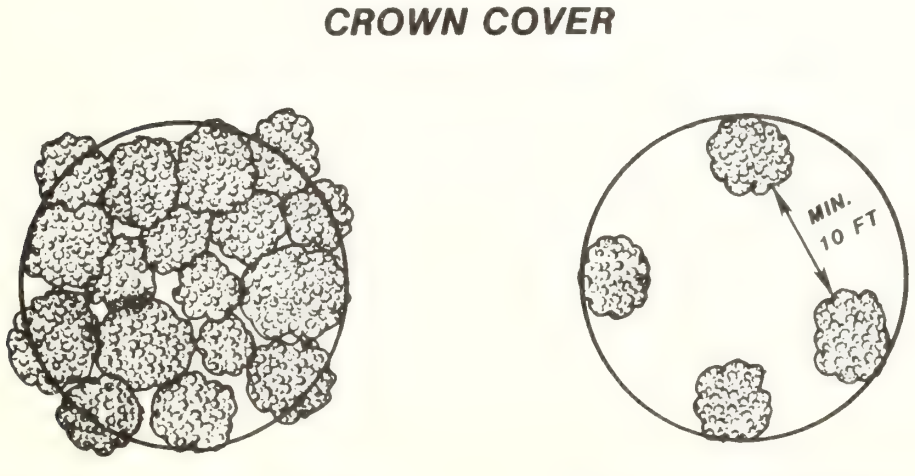
Thinning is an important silvicultural technique for reducing fire hazard (Coulter 1980). Thinning should remove enough trees to prevent the crowns from touching (fig. 3). In high density stands this may require removal of over half the trees--in low density stands only a few may have to be removed. To be on the safe side, a good rule of thumb is to remove enough trees to reduce crown cover to less than 35 percent with a minimum of 10 ft of open space between crowns (Dennis 1983). Crown cover is the percentage of area covered by tree crowns if one were looking at it from above (fig. 3). Retaining greater amounts of crown cover increases the probability of fires spreading laterally through the crowns.

Stands should be thinned for a minimum of 2 tree heights each direction from the home if on level terrain. If the home is on a slope the hazard increases because hot gases flow upslope, preheat the fuels, and increase the probability of ignition near or on the home (Coulter 1980). As a result, for treatments to be equally effective on slopes, treatment distances from the home must be 1½ to 2 times larger on a 30 percent and 2 to 4 times larger on a 55 percent slope than on level terrain (fig. 4). Treatment distance below the home increases from the recommended 2 tree heights on level terrain to 8 tree heights on the 55 percent slope.

Also included in the thinning operation should be the removal of those trees immediately around the home for about 30 ft in each direction if on level terrain, but, like the thinning recommendations, proportionately more for homes on slopes.

Thinning can often be done at a profit to the homeowner if the trees to be removed are large enough to make lumber, poles, posts, grapestakes, pulpwood, firewood, or other useful products. If not, some expenditure of time and money may be needed. An extension forester or consultant forester should be contacted for advice on thinning operations if the homeowner is unfamiliar with the process.

Some precautions are in order. Thinning can result in additional tree losses due to wind damage if the original stand is very dense and it is opened too wide. To reduce this problem, a two-stage thinning is advised, with the initial thinning removing about one half to two thirds of the desired amount followed by another removal 5 to 10 years later. Generally, the largest trees will be the most windfirm and, if generally healthy, should be retained as leave trees. To avoid buildup of bark beetles and fire hazard, slash created by the thinnings should be disposed of soon after thinning.



NEAR COMPLETE COVER

< 35% CROWN COVER

igure 3--Stands should be thinned to reduce crown cover to less than 35 percent of a minimum of 10 ft etween crowns. This greatly reduces the probability of fires spreading laterally from crown to rown.

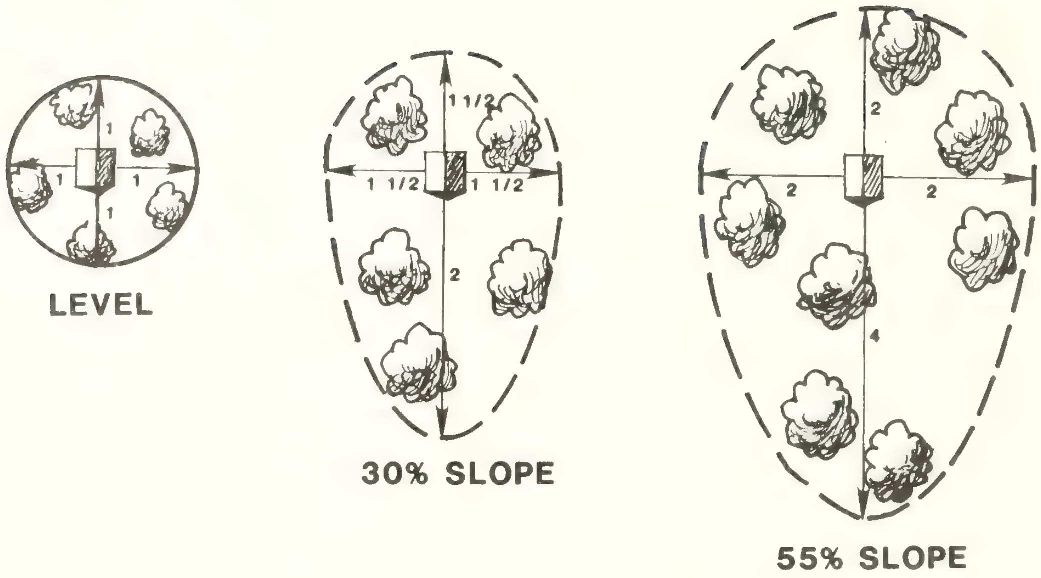


Figure 4--Increasing slopes require increased treatment distances to be equally effective. Recommended distances for level terrain should be multiplied by the factor shown. For example, to be equally effective distances downslope from the home must be increased four-fold on 55 percent slopes when compared to level terrain.

Some expected benefits, in addition to reduction in fire hazard, include an increase in tree vigor and growth, pleasing appearance of individual trees and the stand, and resistance against insects.

Pruning is another important silvicultural technique that can be used to reduce fire hazard for homes in the forest (Fahnstock 1971). For fire hazard reduction, pruning's primary purpose is to increase the distance between the lowest part of the crown and the forest floor. This reduces the probability that surface fires will spread into the crowns where they are very difficult to control. Pruning should remove both live and dead portions of the crown up to 10 ft above the ground (fig. 5) and should be done the same distances from the structure as prescribed for thinning.

Another very effective method of limiting the spread of surface fires both laterally and vertically into the main tree canopy, is removal of understory trees--usually fir trees with long full crowns that extend close to the ground. These trees are a key rung in the fire ladder between the surface fuels and crowns of the overstory trees. Without their removal, surface fires can readily spread from the forest floor to the small, medium, and large understory trees and from there to the main canopy. This connection must be severed by removing these understory trees. If the homeowner elects to retain some of these understory trees, they should not be left in clumps, should be a minimum of 12 ft apart, and should not be under the canopy of a taller tree. Treatment distances from the structure should be the same as those for thinning.

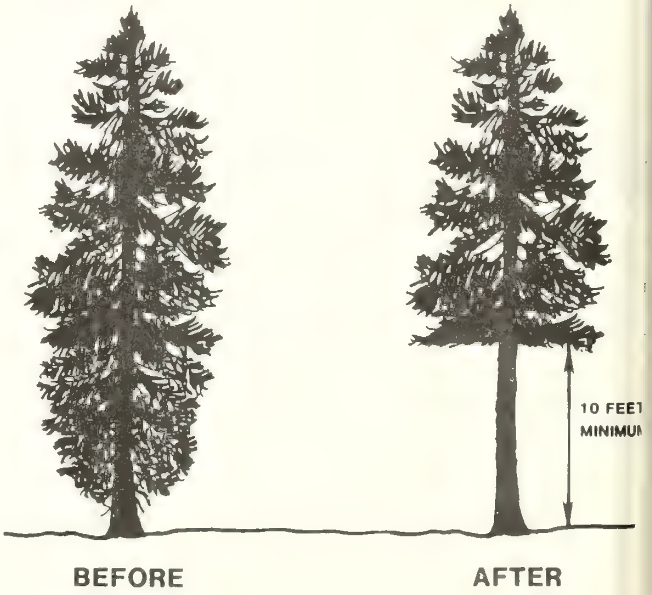


Figure 5--Pruning should remove the live and dead branches a minimum of 10 ft from the ground. This reduces the probability of surface fires spreading into the crown.

Dead Organic Material--This material is the primary fuel for carrying a fire along the forest floor. Most of it must be removed if the fire hazard is to be reduced significantly. The thinning and pruning operations mentioned in the earlier sections also contribute significantly to fuel loading, so the operations of thinning and fuel reduction should accompany each other.

Dead standing and down tree trunks should be removed. Often, these are useable for firewood. In some cases, standing dead trees may be reserved for aesthetic or wildlife purposes. If so, care must be taken to remove all flammable material near their base. Smaller branch materials should be removed from the site either by piling and burning them at a safe time of the year or physically removing them to a location safely away from the home.

Finer twigs, needles, and duff layers should be reduced. In some cases where the property is not extensive, this can be done by raking or some other method. In other cases, the best approach is to remove these fuels from around the remaining trees, then prescribe burn the area under safe burning conditions with the close direction of specialists in this type of operation. Having accomplished this successfully for the first time, periodic burning of accumulated needles and other fuels can be done much more easily because fuels will usually be less abundant. This treatment should be done for the same distance from the home as that described for thinning.

Other Vegetation--Trees, both living and dead, account for most of the fuel in conifer forests. However, other vegetation such as shrubs, grasses, and forbs also provides some fuels, particularly at certain times of the year. After the grasses, leafy forbs, and shrubs have matured, they become a hazard because fires can move rapidly through them and ignite the heavier woody fuels.

If shrubs are fairly abundant near the homes, and if they are the type that are highly combustible, such as manzanita, they should be removed or thinned so they are not near each other or near trees. This problem is most common in the ponderosa pine zone.

Grasses that mature and dry out early in the growing season can also be a significant problem, particularly in the ponderosa pine and lower portions of the mixed conifer zones. If feasible, grasses near the homes (30 ft or so) should be replaced with a watered lawn that stays succulent most of the year. If water is not available grasses should be mowed and cuttings removed once or twice during the growing season. This tends to keep grasses more succulent and removes part of the fuel ladder.

Treatment Combinations--The treatments just described alter the character of the live trees and stands, the dead organic matter, and the other vegetation. Figures 6, 7, and 8 graphically portray those combinations of treatments and show how treatment needs are somewhat different in the three conifer forests--ponderosa pine, mixed fir, and lodgepole pine.

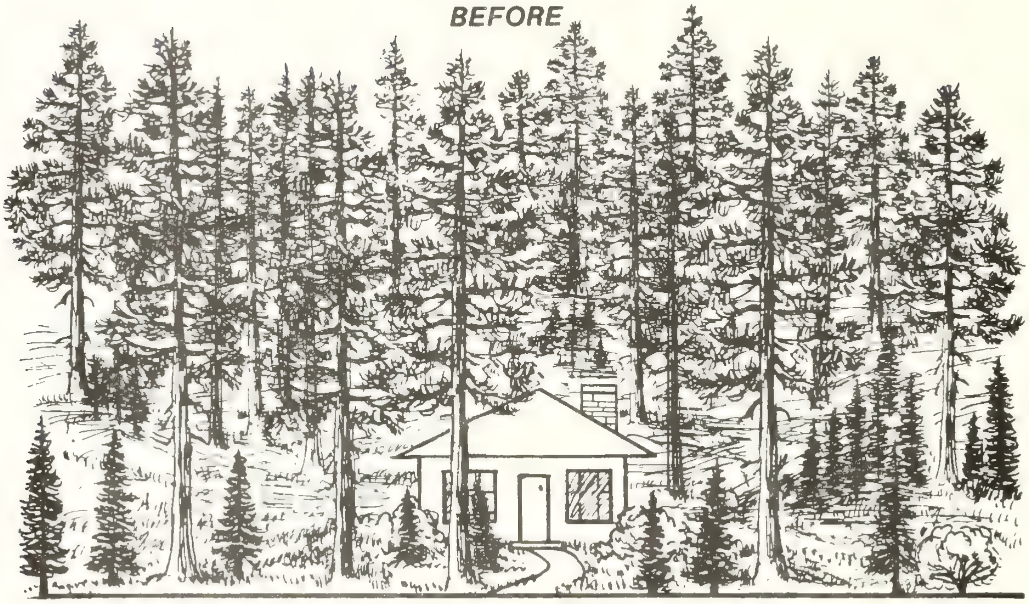
Community Efforts

Although this paper emphasizes what individual homeowners can do in the way of cultural practices to reduce fire hazard, much can be done collectively by homeowner groups (Dennis 1983). The same principles apply to groups of homes as individual homes, but community efforts can have a compounding effect in reducing the overall fire hazard. One fruitful community effort is to develop fuelbreaks around and within subdivisions or communities (Green and Schimke 1971). This can be done in different ways. For example, fuelbreaks are generally on easily accessed strips of land that are suitable for fuel reduction treatments including thinning, pruning, removal and spacing of understory trees and shrubs, and the disposal of woody fuels. This creates an open, parklike condition that is both attractive and safer from spreading fires. Another desirable method is to convert strips of land from natural tree, shrub, and grasslands to green parkways of watered lawns. Either method can be blended in esthetically by following natural contours or existing fire access roads.

Thus, whether done individually or collectively, there are a number of cultural practices that can be used to reduce fire hazard. If designed properly, they can have the added benefits of healthier vegetation and a more esthetically pleasing natural setting.

PONDEROSA PINE

BEFORE



TREATMENT

THINNED & PRUNED
UNDERSTORY TREES REMOVED
SHRUBS REDUCED
WOODY FUELS REMOVED
GRASSES CUT

AFTER

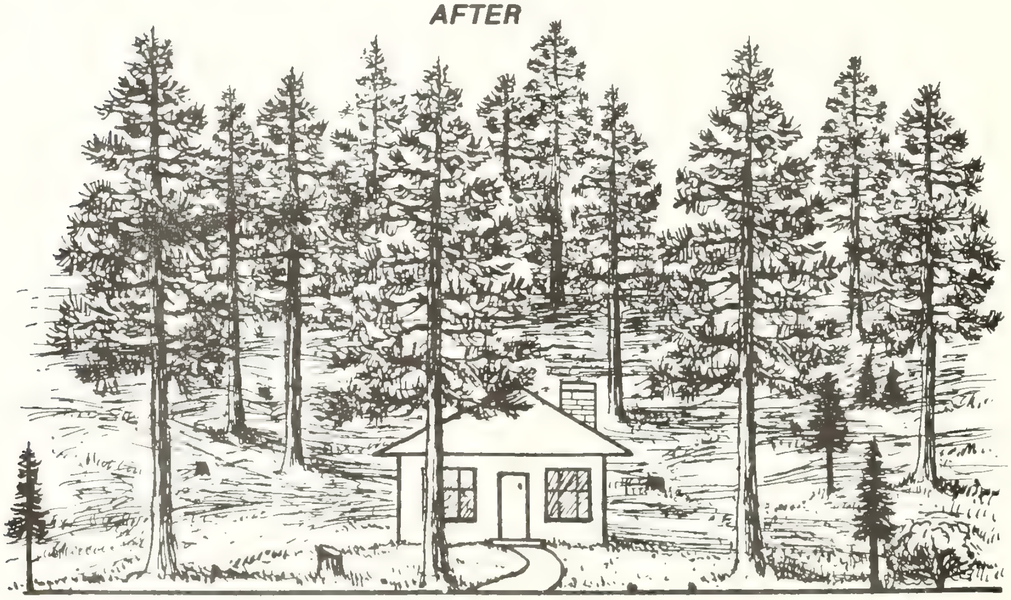
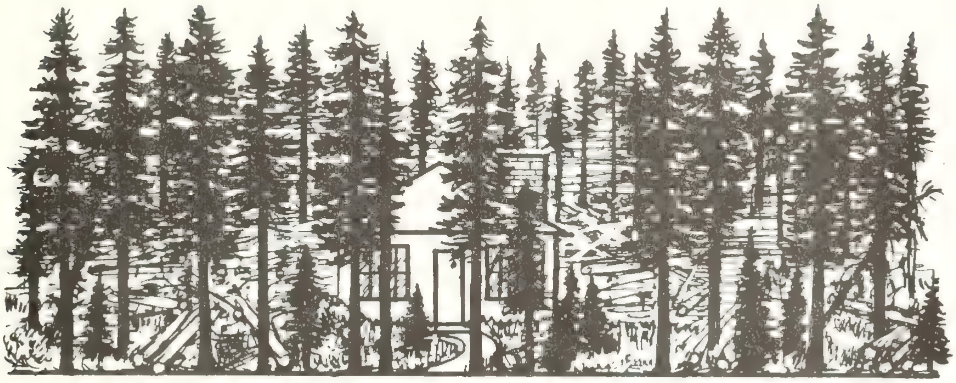


Figure 6--To reduce fire hazard, ponderosa pine forests will usually require a moderate amount of thinning and pruning, some understory and shrub removal, a modest amount of woody fuel removal, and usually grass removal or replacement with bluegrass.

LODGEPOLE PINE

BEFORE



TREATMENT

- THINNED
- MINOR PRUNING
- WOODY FUELS REMOVED

AFTER

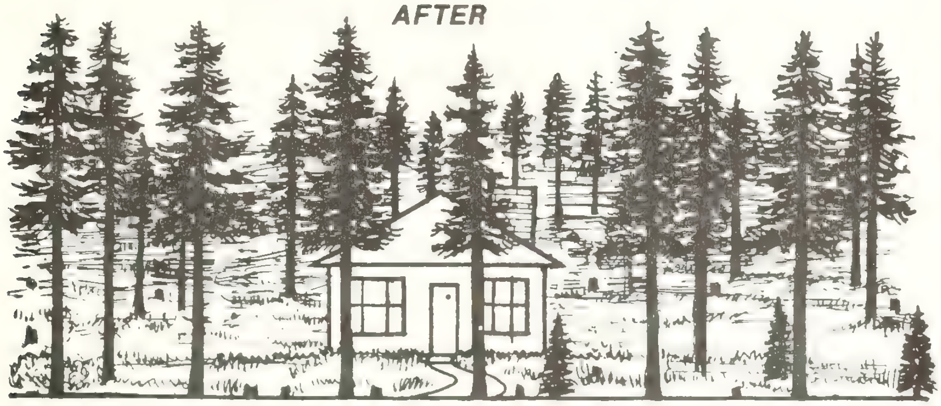
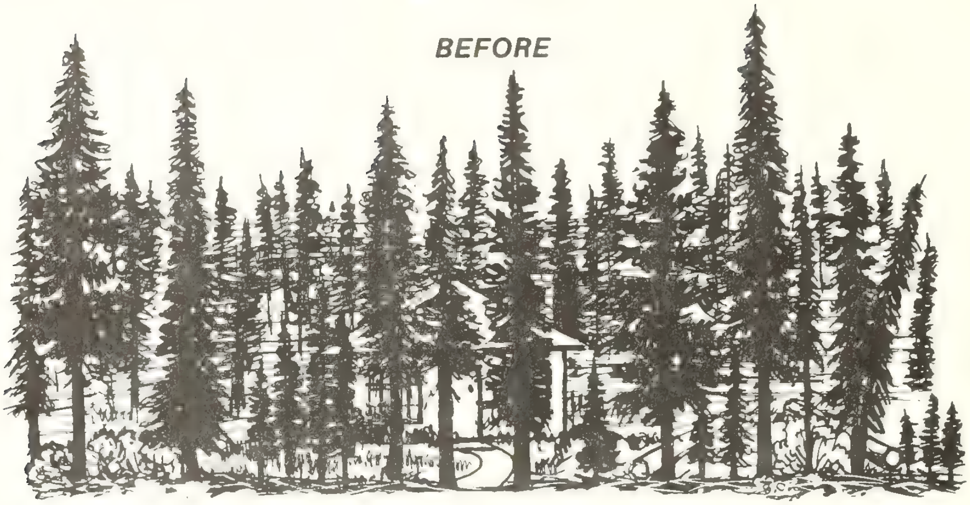


Figure 7--Reducing fire hazard in mixed fir forests normally requires a significant effort because stands are usually dense and require a lot of thinning, trees have long crowns that require a lot of pruning, understory trees and shrubs are usually abundant and need to be removed, and abundant woody material and duff need to be substantially reduced.

MIXED FIR



TREATMENT

- THINNED & PRUNED
- UNDERSTORY TREES REMOVED
- SHRUBS REDUCED
- WOODY FUELS REMOVED
- DUFF REDUCED

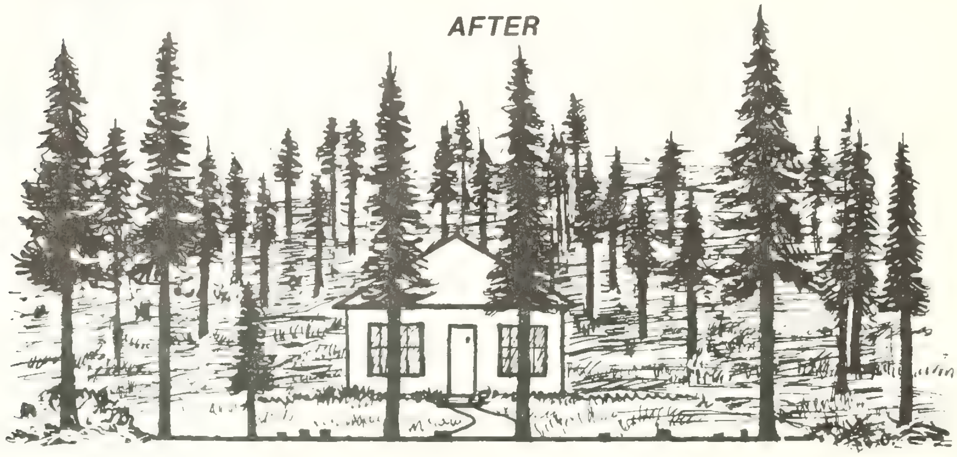


Figure 8--Reducing fire hazard in lodgepole pine forests will normally require a lot of thinning and removal of dead woody material but only a minor amount of pruning and understory tree removal.

SUMMARY

Cultural practices can greatly reduce fire hazards around homes in the grass, shrub, and forested lands of the interior West. Reducing the fire hazards will also decrease the probability of losing a home to wildfire. At this point, there is no 100 percent foolproof cure for the fire hazard headache, but the cultural practices described in this paper, along with recommendations from other disciplines, should go a long way in relieving the pain. Most of the recommendations in this paper make just plain common sense if you have an understanding of fire behavior and the fuels that feed the fire. At this point, there is no mathematical equation that can predict the probability of a home surviving a threatening fire under each and every vegetation type, fuel condition, topographic position, type of home construction, and the like. However, there is no doubt that the probabilities of a house surviving a threatening fire can be increased substantially if the cultural practices suggested here are followed.

The cultural treatments described in this paper are additive. Completion of each treatment increases the probability of home survival. For example, pruning alone is helpful but it is far more effective if it is accompanied by thinning, understory tree removal, grass and shrub treatments, and removal of tree trunks, branches, and litter. Some treatments have to be accompanied by others or they lose their positive effect. For example, thinning without subsequent slash disposal can create a higher fire hazard than no thinning at all.

In many cases, cultural practices will enhance the appearance of the homesite and the owner may adopt all the options, substantially reducing the fire hazard to his home. However, in some cases, the application of all of these recommendations may alter the character of the home site so much that it no longer meets the owner's objectives. In this case, the owner may choose to use only those stand culture practices that help reduce hazard but don't greatly alter the appearance of the stand, with the full knowledge that fire hazards may remain substantial.

In brief, the following cultural practices can be used to decrease fire hazard to homes in wildland situations:

1. Thin the forest to 35 percent or less crown cover or a minimum of 10 ft of space between crowns to reduce spread of crown fires.
2. Prune trees to 10 ft or more above the ground to reduce the incidence of surface fires getting into the tree crowns.
3. Remove understory trees or space them widely enough to reduce the chances of surface fires igniting them and they in turn the main forest canopy.
4. Clean up dead woody material including that already there, and that accumulated in the above operations to reduce incidence and intensity of surface fires.
5. Remove or widely space combustible shrubs and reduce the grasses that mature early to reduce the incidence of fast-moving surface fires.
6. Remove or thin shrubs so that the intervening space is at least 5 times the height of the plants.
7. Mow and rake up grasses periodically during the growing season to reduce the incidence of fast-moving surface fires.
8. Where collective efforts are possible, build fuelbreaks with thinning or clearing around and within communities.

REFERENCES

Barney, M. A.; Frischknecht, N. C. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27: 91-96.

Brown, James K. 1982. Fuel and fire behavior prediction in big sagebrush. Res. Pap. INT-290. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Coulter, J. Bruce. 1980. Wildfire safety guidelines for rural homeowners. Fort Collins, CO: Colorado State Forest Service, Colorado State University, 23 p.

Dennis, Frank C. 1983. Fuelbreak guidelines for forested subdivisions. CSFS 102-1083. Fort Collins, CO: Colorado State Forest Service, Colorado State University. 16 p.

Fahnstock, George R. 1971. Rating forest fire hazard in residential developments in Colorado forests. Fort Collins, CO: Colorado State Forest Service, Colorado State University. 29 p. Mimeo.

Fischer, William C.; Books, David J. 1977. Safeguarding Montana's forest homes: lessons from the Pattee Canyon fire. Western Wildlands. 4(1): 30-35.

Freedman, June D.; Fischer, William C. 1980. Forest home fire hazards. Western Wildlands. 6(4): 23-26.

Green, Lisle R.; Schimke, Harry E. 1971. Guides for fuel breaks in the Sierra Nevada mixed-conifer type. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 14 p.

Guth, A. Richard. 1987. Forests and people--wildfire strikes home. American Forests. 93(9 and 10): 54-57 and 68.

Lotan, J. E.; Alexander, M. E.; Arno, S. F.; French, R. E.; Langdon, O. G.; Loomis, R. M.; Norum, R. A.; Rothermel, R. C.; Schmidt, W. C.; Van Wagtendonk, J. 1981. Effects of fire on flora. Gen. Tech. Rep. WO-16. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 71 p.

PROTECTING PEOPLE AND HOMES FROM WILDFIRE IN THE INTERIOR WEST:

MEETING THE CHALLENGES

Tom Borden

I'm the wind-up speaker. When I'm through, that's the clue you can get off your duff and head for home. And then I can head for Colorado for the opening of elk season Saturday morning.

Dan Bailey asked me thank everyone who has been a participant or has sponsored this particular symposium. And so I won't forget, I will do so now. Those people and organizations include the U.S. Forest Service, the National Fire Protection Association, the Society of American Foresters, the National Association of State Foresters, the University of Montana, the Montana Department of State Lands, and Montana Extension Forestry. With special thanks to the steering committee and the program committee. And then, let me add, as an addendum, the one person who acted as the chief wrangler for this whole operation: Dan Bailey. I think everyone, including and particularly Dan, needs to receive a round of applause.

Fortunately for you, I do not have a written speech because when you're the one who has to wrap up a conference, you listen, jot a few notes, and provide a summary, and there's nothing to read. Often times, however, when I see someone come forward wearing glasses, I say 'Oh, My God, he's going to read a speech.' But I do need them to see my notes. I'll follow these notes fairly closely because if I don't, I'll get off on tangents like, for instance, the National Association of Homebuilders comparing our particular interface problem with the 50,000 people who are killed annually on the highways. And saying 'well, the rural-urban interface really isn't that big a deal, is it? But that's like saying, 'the 50,000 boys we lost in Viet Nam over 6 or 8 years doesn't compare with the 50,000 auto deaths a year, and the earthquake in California isn't much of a problem either.' I remember talking to my boss, the president of Colorado State University, about my budget request and how important it was. He looked at me and said "Tom, do you realize that the State Forest Service is only 2 percent of the university?" I was taken aback. But then I realized that just about every department of the university was 2 percent or less of the total. Regardless, the urban-rural interface is a serious and growing problem.

As I listened, the program bore a significant resemblance to how a speech is prepared. There is an attention step, a need step, a satisfaction step, which takes care of the need, a summary and illustrations, and then an action step at the end. Well, by golly, there is no point in talking about the attention step because this particular year's fire experience drew everyone's attention to the interface problem. The turnout, which I saw here, I didn't expect at all, and frankly, I didn't expect more than 25 to 50 people to be here for the last hour of this last session. And here you are. I'm impressed, and I know that we, who are on the last day, thoroughly appreciate your staying with us. Another thing I noticed in this audience was the rapt attention that you folks paid to the speakers. Many of the programs' presentations were just superb, others were not as superb, but there you sat, listening to every word, many of you taking notes.

Well, that takes care of the attention step. The need was obviously there for the same reasons. There were people who were saying 'there's got to be a better way of dealing with the interface problem'. We have got to avoid the "Chinese firedrill" that my people and I went through. I can't imagine a conference being more timely than this one. The need is there. In fact, when I arrived Sunday from Kalispell, a great plume of smoke hung over Agnes Creek on the outskirts of Missoula. It was a fitting beginning to this conference.

What can be done to satisfy the need? Or, in other words, what's the solution to the problem? Your heads ought to be full of ideas on what to do when you get home.

We listened first, as I considered it, to the background and the considerations, the political scene--Senator Melcher and Representative DeFazio. Let me add as an aside, with all my years of experience in listening to Senator Melcher, do not hold your breath while he gets money for the fire program. Being retired at this particular time, on my own and living in another state, I can make that statement. There was the role of the Federal Emergency Management Agency. And another aside: don't hold your breath with that outfit either, because they don't produce but rarely. They

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Closing Remarks made at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Tom Borden is Vice President, American Forestry Association, Fort Collins, CO.

compare our fire interface problem with earthquakes, big floods, and hurricanes. When it gets down to some piddly little fire that only costs a million dollars, well, 'we really don't see an emergency.' That's FEMA's frame of reference. Wildland home insurance was another important aspect of the program of these last three days.

Nevertheless, what can be done? And in a nutshell, I wrote this down, "Only local citizens, wildland homeowners in particular, can bring about firesafe conditions.' I learned long ago, especially as a forester, you never say never, you never say only. But, generally speaking, I think that's the message that came across. We must build from the grassroots, the people on the ground, if we're going to actually get something done in this particular endeavor. If you have the grassroots support, only then will the local, state, and federal governments respond. The Missoula County Commissioner advised that a coalition of people meet, discuss solutions, and come up with a plan of action for whatever it is they want. In this interface case, it would include homeowners, realtors, and firemen.

Gaining the grassroots support and demands for action led to the 'how-to's'. Real life examples presented by the Lee, Severson, and Hodgson team, Montague and LaBlanc on the Sierra front, video tapes of various programs, and the successes in the various states here in the West, were followed by examples of workshops helping homeowners and developers understand how to communicate with politicians, with the media, and how to obtain consensus in methods of protecting the interface properties. And, this morning's presentations of former secretary Rupert Cutler's population dynamics, followed by the identification and role of various planning and zoning devices relating to the interface situation were important facets. A case was made for voluntary adoption of, and voluntary compliance with, firesafe practices and other desirable conservation purposes. One illustration highlighted the progress in Jefferson County, Colorado, emphasizing the regulatory aspects and the outstanding cooperation between the county and State Government. We also heard about the architectural concerns and practices, the positive and negative stances towards the interface by the National Association of Homebuilders, and the opportunities for utilization of fire engineering specialists.

But one condition, and these are my personal comments, was presented which needs a little further elaboration. If there's a limiting factor, I suspect this may be the one. Can anyone remember the first four letter word they learned? Right after 'Mommy' and 'Daddy'? It starts with the letter "M". I'm not going to play games with you. The word is MINE. M-I-N-E. My mommy, my daddy, my bottle, my bed, my wagon, my books, my school, my team, my job, my agency, my company, my authority, and, as you grow older, my responsibility.

A mother looks out at little children playing in the back yard and says "Share, quit that fighting--share." And one child says, "You touch my GI Joe one more time and I'll bust you in the nose. He's mine!" It reminded me of two vultures. Some cartoonist drew two vultures with red eyes and, of course, they were all black. He didn't know they were scavengers, portraying them as raptors. These birds were perched on a tree limb and one says to the other "Patience, hell, I'm going to go kill something." That's kind of what I think of when I think of 'mine.' Now, you may say, "Oh, for Pete's sake, we're going to get into the turf bit again; we've heard enough about that. No, I'm not going to give you a similar lecture, for, you see, competition and turf is at the heart, the very center, of our American way of life. Without it, we as a nation could not have survived for 200 years. In the city of Fort Collins, we have the Colorado State University with it's own little police department. Then there is the City Police force. The Sheriff has his boys out on the county roads, and the State Highway Patrol does it's thing on the interstates and the state highways. Every one of them says to the other "You keep the hell out of my jurisdiction." What a waste of money! Except, honestly, I hope they continue to do it. An alternative, in our very, very expensive way of life in the United States, is to have an all encompassing state-run police force. It doesn't take much thought to realize that the federal government could do it, too; one federal police force doing everything. Think of the money we'd save! I hope they never get together. I hope they fight turf battles forever and ever. But there are other, more positive examples.

Before World War II the Department of the Army and the Department of the Navy would go before the appropriations committees in Congress, and they'd fight. The Navy would ask for more aircraft carriers. And the Army generals would come along and say, "Aircraft carriers, hell, we need tanks." Neither military service was successful. Broomsticks, for instance, were used for rifle training. But look at them now! They're part of the Department of Defense. Army, Navy, Air Force, Marines. Coast Guard, I guess, is in there, too. And, would you like to know, have you any idea what their budget and their appropriations are? I don't know, but it's the biggest item in the national budget. You know, the dollars spent for one wing of a fighter could do a lot in the interface. The services are together but they're able to maintain their identity. They're still competitive but they're together and they work together, like it or not. And, they have all the money they need, maybe more than they need.

Back to Colorado. We have Colorado State University, Colorado University, Colorado School of Mines, University of Northern Colorado, and others. They used to fight without great success for funds in competition with each other before the legislative budget committees. Finally, a Commission on Higher Education has been given the teeth to be the overseer of the university system. I'll bet you any amount that over the next five years, the appropriations for higher education and individual institutions will increase significantly over the levels of 1987.

We have a mountain pine beetle problem in Colorado. In the 70's, hundreds of thousands of trees were dying. And we, as individuals and agencies, the State Forest Service, the U.S. Forest Service, the BLM, and others, were all trying to fight it alone. We didn't start to win until we all got together, the homeowners, the U.S. Forest Service, the State Forest Service, the County Commissioners, and even the city of Boulder in this case. An interface team, as it related to mountain pine beetle, bore fruit you can't imagine. Comparatively, we had money coming in from all quarters, and we worked together to ameliorate the situation. Notice I didn't say we cured the problem. But we sure put a crimp in it. One of the practices we used was to cut infested trees that were becoming the hatchery for the next year's beetles, cutting and bucking them up, putting them under plastic, and injecting ethylenedibromide in a fumigation process. It worked very well. But one landowner in one little mountain community, said "I don't believe in control, it's part of nature's way." He went to church one Sunday morning, and that afternoon when he returned home, his trees were gone. The neighbors had taken care of the problem, announcing "you're going to be part of the game."

Well, mountain pine beetle was a crisis situation and the interface is a crisis situation, too. And it can be addressed in much the same way. Now, my charge to you as I get down towards the end of my comments, is as follows: Armed with what you've learned, and enthused as you obviously are, with the possibilities you've discovered or had reinforced, and recognizing that the folks back home haven't been here and will need to be informed and convinced, you must become a leader. You need to get together with others attending this meeting with you from your community or your region or your area and ask "What is it we can do?" If you can't be THE leader, be A leader, or be a catalyst, to bring about some sort of direction to the interface problem. Put together a team and make it MY team. Do what Stauber is going to do on the San Bernardino National Forest, or Hammond in the Black Hills. They're going to put together symposiums like this one. They'll get the local people involved, and maybe some outsiders, to come in and do some of the things that have been done at this particular session. It won't be easy, but when when you run into roadblocks, and you become discouraged, and ill at ease, and defeated, why don't you use the motto that I've used all my career, and sometimes it works: "Some things are impossible; others take a little longer."

SESSION 7--POSTER PAPERS

William C. Fischer, Coordinator
Research Forester
Intermountain Research Station, Forest Service
U.S. Department of Agriculture
Missoula, Montana

FIGHTING FIRE WITH FIRE

Theodore E. Adams, Jr., Gary Reece, and Walter L. Graves

ABSTRACT: This illustrated presentation, using an animated (TV video tape) and static (enlarged color photographs) format, shows how a Southern California community used prescribed fire to reduce a wildfire hazard at the boundary with chaparral brushlands. Included is a brief narrative describing the situation and the cooperative effort needed to achieve success and reduce potential property losses and possible loss of life.

In three successive years, Tierrasanta, a southern California community near San Diego, was threatened by wildfire. This suburb borders chaparral brushlands where the risk from wildfire is great. The fires came dangerously close, but each time they were suppressed through the efforts of local fire agencies and the California Department of Forestry and Fire Protection (CDF).

In 1982, homeowners in the El Dorado Hills area of Tierrasanta decided they had had enough! Through their homeowners' association, they solicited help from local and federal politicians.

In searching for a solution to the wildfire hazard, reduction of the fuel load by mechanical and chemical brush control measures was considered and discarded. The alternative selected was prescribed fire--fire used as a tool under controlled conditions to achieve a particular management objective.

The selection of fire was appropriate, because fire is a natural tool. Chaparral brushlands are a product of fire; over several millions of years, fire has influenced the development of California brushlands.

The political contacts arranged for project funding, and the Watershed Division of San Diego County's Department of Agriculture organized the prescribed fire. The fire was conducted under weather conditions that permitted a safe burn, burning away from homes and into the brush.

The cleared area, now a fuel break, was burned for less than $10 per acre, cheap insurance for the $150,000 homes it will protect for several seasons.

Creating the El Dorado Hills fuel break produced another benefit; it provided an opportunity to train local fire protection agencies in the use of prescribed fire for fuel management. Fire fighters from four communities and a military installation participated. They were supported by state and local groups experienced in fighting wildfires, the California Conservation Corps, and the City of San Diego's Wildland Fire Fighters.

Prescribed fire for reduction of the wildfire hazard on private lands in California has been in use since creation of the Chaparral Management Program (CMP) in 1980. This program, part of the more comprehensive Vegetation Management Program administered by the CDF, emphasizes fuel management for hazard reduction. But it addresses other needs as well: watershed protection, wildlife habitat improvement, and range forage improvement for livestock production. Use of fire for the latter provided the foundation on which the CMP is based.

The CMP targets about half the 10 million acres of California shrublands for which the CDF is responsible. Making this vast area less subject to devastating wildfires is a formidable task. But the CDF is addressing this challenge through burning on a rotating schedule to create a mosaic of different age classes. Sustaining momentum of the new program is another challenge. This will depend on public support. And this can be achieved only with an investment in education.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Theodore E. Adams, Jr., is Extension Wildlands Specialist, University of California, Davis, CA; Gary Reece is Chief, Agricultural Services, San Diego County Department of Agriculture, San Diego, CA; Walter L. Graves is Farm Advisor, University of California Cooperative Extension, San Diego, CA.

HELP WITH MAKING CROWN FIRE HAZARD ASSESSMENTS

Martin E. Alexander

BSTRACT: This paper offers some suggestions and ield guides with respect to the operational pplication of C. E. Van Wagner's (1977. Can. J. or. Res. 7: 23-34.) theory to calculate the hreshold conditions for the start and spread of rown fires in conifer forests. Three categories of rowning are recognized (passive, active, and ndependent); they are determined by three crown uel properties (live crown base height, foliar oisture content and bulk density) and two haracteristics of fire behavior (spread rate and urface intensity).

NTRODUCTION

hree main types of forest fire are commonly ecognized on the basis of the fuel layer(s) nvolved in the combustion process:

- Ground or Subsurface Fire
- Surface Fire
- Crown Fire

lthough they may appear to spread independently, rown fires advance through the crown fuel layer ormally in direct conjunction with a surface fire. rowning forest fires are very exciting natural henomena but pose a potentially serious threat to ife and property in wildland areas (Rothermel and itch 1986; Webster 1986; Wilson and Ferguson 1986; ot and others 1987). The transition from a surface re to a crown fire is also obviously of great ignificance to fire managers since crowning nerally represents a level of fire behavior that ormally precludes any direct suppression action. he conditions under which crown fires are likely to cur have been identified in a general way (Beale d Dieterich 1963; Fahnestock 1970; Rothermel 83). More fundamental knowledge about the physics such wildfire phenomena in the wildland/urban terface has recently been identified as a critical re research need (Davis and Marker 1987). In the antime, what information is currently available w to assist land managers with the job of jectively appraising the likelihood of crown fire velopment on an area or site-specific basis? More an 10 years ago, Van Wagner (1977) proposed some mple theory, supported in part by empirical field servations, regarding the conditions for the itiation and sustained propagation of crown fires conifer forests which could be applied to a variety of fire management issues, including the wildland/urban interface problem. The purpose of this paper is to outline, in practical terms, the possible application of Van Wagner's crown fire classification scheme and model to the task of evaluating crowning potential. This includes the author's synopsis of Van Wagner's theory (with a minimum of equations), supplemented with several graphical and tabular aids to facilitate the interpretation of the theoretical concepts, designed with the fire manager in mind[1]. However, a certain level of familiarity on the part of the reader with the science of wildland fire behavior and the art of its prediction is assumed. Van Wagner's (1977) journal article should of course be consulted for clarification of any technical details given here. The International System of Units (SI) is used throughout; a list of SI-to-English unit conversion factors is included near the end of the paper. However, the English unit equivalents of all equations are given.

BACKGROUND INFORMATION

Fire intensity as used in this paper refers to frontal fire intensity (I), which is synonymous with Byram's (1959) fireline intensity (Merrill and Alexander 1987), defined as "the rate of heat energy release per unit time per unit length of fire front" (Merrill and Alexander 1987). The equation used to compute I (kW/m or Btu/sec/ft) is as follows (after Byram 1959):

$$I = \frac{HWR}{60} \qquad (1)$$

where, H = net heat of combustion (kJ/kg or Btu/lb), W = quantity of fuel consumed in the active flaming front (kg/m^2 or lb/ft^2), and R = linear rate of spread (m/min or ft/min). Flame length (Alexander 1982, p. 351, figure 1) is generally considered a surrogate measure of frontal fire intensity. The most commonly accepted equations are (from Alexander 1982 and Byram 1959, respectively):

$$L = 0.0775(I)^{0.46} \qquad (2)$$

$$L = 0.45(I)^{0.46} \qquad (3)$$

where, L = flame length (m and ft, respectively) and I = frontal fire intensity (kW/m and Btu/sec/ft, respectively).

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per presented at the Symposium and Workshop on otecting People and Homes from Wildfire in the terior West, Missoula, MT, October 6-8, 1987.

rtin E. Alexander is Fire Research Officer, rthern Forestry Centre, Canadian Forestry Service, monton, AB.

[1] Enlargements and English unit versions of Figures 1 to 5 plus the Appendix are available upon request from the author at the following mailing address:
5320 - 122 Street, Edmonton, Alberta, Canada
T6H 3S5.

VAN WAGNER'S CLASSIFICATION SCHEME AND MODEL

Classes of Crown Fire

According to Van Wagner (1977), crown fires in conifer forests can be classified according to their degree of dependence on the surface phase and the criteria could be described by several semi-mathematical statements. Approximate definitions for the three types of crown fires are as follows:

> Passive Crown Fire - A fire in which trees "torch" as individuals, but rate of spread is controlled by the surface phase.
>
> Active Crown Fire - A fire that advances with a well-defined wall of flame extending from the ground surface to above the crown fuel layer.
>
> Independent Crown Fire - A fire that advances in the crown fuel layer only; the surface fire of course lags some distance behind the leading edge of the crowning phase.

Other crown fire terminology exists (for example, Brown and Davis 1973; Merrill and Alexander 1987). A passive crown fire is basically not that different from an intense surface fire and probably most crown fires are of the active class (Van Wagner 1983). The class of crown fire to be expected in a conifer forest on any given day, according to Van Wagner (1977), depends on three simple properties of the crown fuel layer and two basic fire behavior characteristics:

- Initial Surface Fire Intensity
- Foliar Moisture Content
- Live Crown Base Height
- Crown Bulk Density
- Rate of Fire Spread

The first three quantities determine whether a surface fire will ignite the coniferous foliage. The last two quantities determine whether or not a continuous flame front can be sustained within the crown fuel layer.

Conditions for the Onset of Crowning

Van Wagner (1977) postulated that vertical fire spread will occur in coniferous forest stands when the surface fire intensity (I_s) attains or exceeds a certain critical surface intensity for crown combustion (I_o) value (kW/m or Btu/sec/ft). That is, when $I_s \geq I_o$, torching or crowning is quite possible. Whereas, when $I_s < I_o$, a surface fire is likely to be the result. Ladder or bridge fuels must presumably be present in sufficient quantity to intensify the surface fire appreciably as well as to extend the height of the flames (Quintilio and others 1977). The SI or metric unit version of the equation to calculate I_o (kW/m or Btu/sec/ft) is as follows (after Van Wagner 1977):

$$I_o = [0.010\ \mathrm{LCBH}(460 + 26\ \mathrm{FMC})]^{1.5} \qquad (4)$$

$$I_o = [0.0030976\ \mathrm{LCBH}(197.90 + 11.186\ \mathrm{FMC})]^{1.5} \quad (5)$$

where, LCBH = live crown base height (m or ft, respectively) and FMC = foliar moisture content (% oven-dry weight or ODW basis). LCBH refers to the distance from the ground surface to the base of the live conifer tree crowns and FMC refers to the moisture content of coniferous tree foliage. Equations (4) and (5) define the amount of energy required to preheat the unburned coniferous foliag to ignition temperature. Graphical representation of equation (4) are given in figures 1A and 1B. Note that the surface fire intensity required for ignition of coniferous tree crowns increases with FMC and HLCB. The importance of moisture content with respect to the ignitability of coniferous tre foliage has been demonstrated many times in the laboratory (see, for example, Fuglem and Murphy 1979; Cohen and others 1987). If the FMC is high, combustion efficiency is reduced and greater amoun of energy are required to bring the foliage to ignition temperature. However, it appears from figure 1A that the natural variation in LCBH would allow for a much greater effect on the flammability of coniferous tree foliage than would the observed variation in FMC (cf. Fuglem and Murphy 1980, p. 35, figure 10). Since frontal fir intensity and flame length are known to be directl related, it is possible, by combining equations (2 and (4) [or (3) and (5)], to infer a critical or minimum flame length for crown combustion L_o (fig. 2). According to figure 2, the flames of a surfac fire do not have to necessarily reach into the tre crowns to initiate crowning; flame height and leng are only equal in the case of no wind or slope (Alexander 1982).

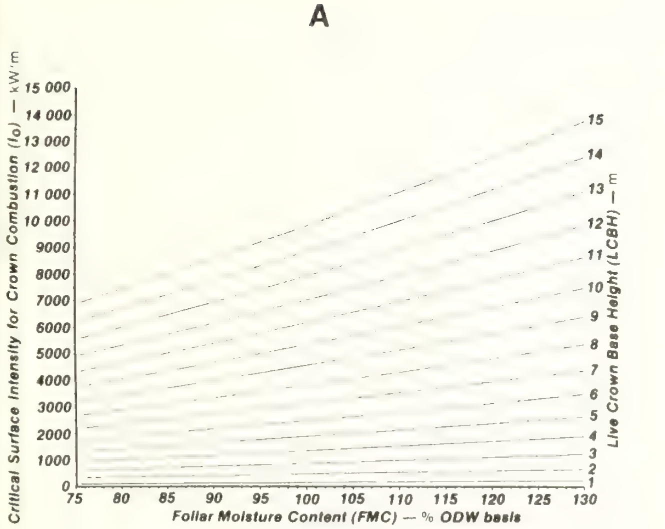
Conditions for Sustained Crown Fire Spread

Presumably some conifer stands are simply not pror or susceptible to sustained crowning because of their low tree density and/or crown fuel density (that is, there is insufficient coniferous tree foliage to support continuous horizontal fire spre in the crown fuel layer). Passive or intermitten crown fires are common, for example, in sparsely-stocked black spruce stands even though the tree crowns extend to the ground surface (Norum 1982). The torching which occurs in a passive or intermittent crown fire simply reinforces the spre rate (that is, the crowning phase of the fire is dependent on the surface phase, the spread of whi will control the fire's spread rate as a whole).

What kind of forest is most likely then to suppor an active crown fire? Presumably there must be sufficient surface fuel to support a substantial surface fire in order to induce crown combustion. Thereafter the surface and crown fire phases adva as a linked unit, but are dependent on each other (Van Wagner 1977). In an active crown fire, both phases contribute significantly to the spread rat Intuitively one would think that there must be a more or less critical value or threshold conditio which must be exceeded in order to sustain a continuous flame front within the trunk and crown space. Van Wagner (1977) theorized that the bulk density of the crown fuel layer must have a lower limit below which active crowning cannot be maintained (fig. 3). This thought has been formulated into the following relation (after Van Wagner 1977):

$$R_o = 3.0/\mathrm{CBD}$$

where, R_o = critical minimum spread rate for acti



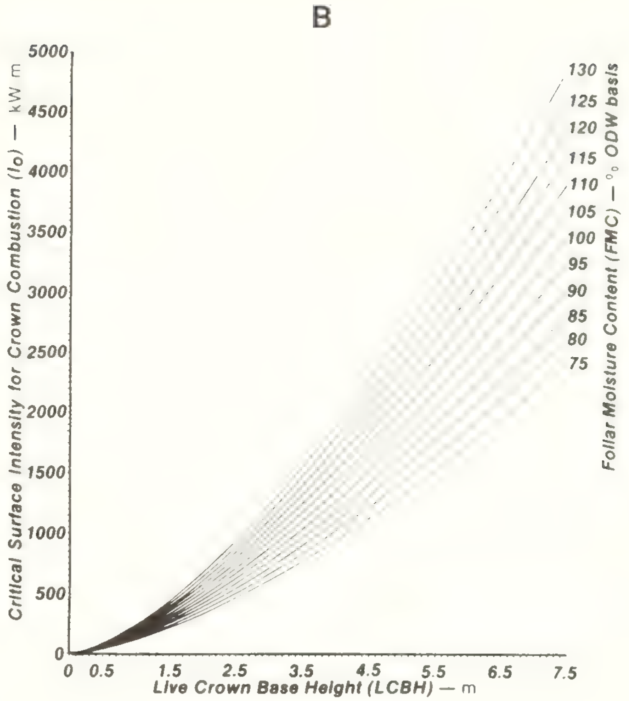
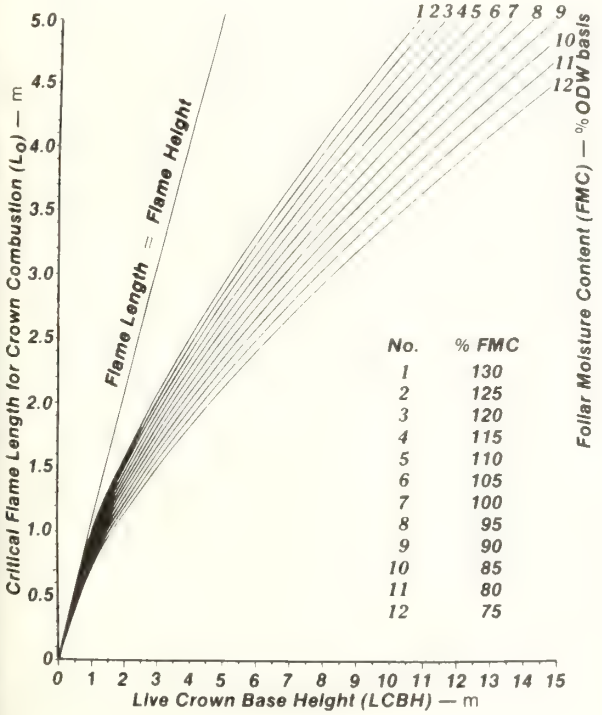
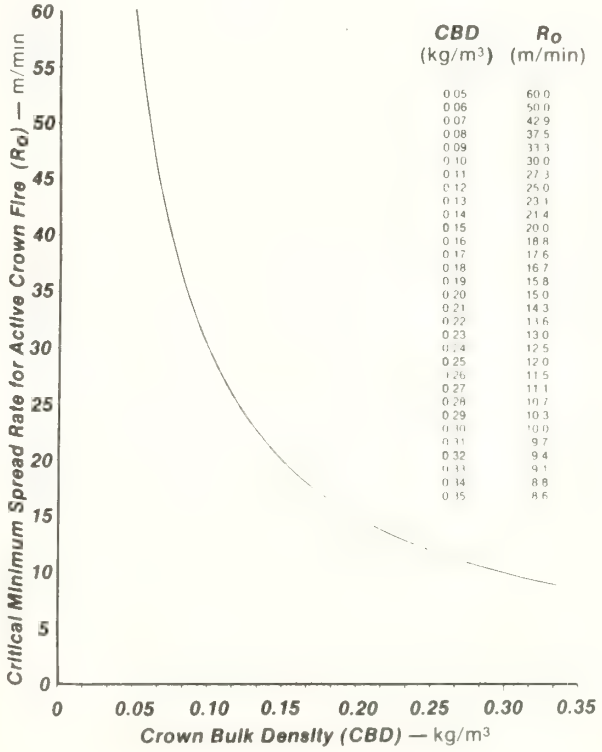


Figure 1--Critical surface intensity for crown com-bustion in coniferous forest stands as a function of A foliar moisture content and live crown base height and B live crown base height and foliar moisture content according to Van Wagner (1977). Sample interpretation: The surface fire intensity required to initiate crowning at a LCBH of 7.5 m and 100% FMC is about 3500 kW/m.



No.	% FMC
1	130
2	125
3	120
4	115
5	110
6	105
7	100
8	95
9	90
10	85
11	80
12	75

gure 2--Minimum flame length for crown combustion coniferous forest stands as a function of live own base height and foliar moisture content based Van Wagner (1977) and Byram (1959). The line of act agreement between flame length and flame height noted for reference purposes. Note that the key the family of FMC curves is given in the accompa-ing tabulation. Sample interpretation: At a LCBH 5 m and 100% FMC, crowning would commence once the rface fire began to generate flame lengths of 2.5 m.



CBD (kg/m³)	R_o (m/min)
0.05	60.0
0.06	50.0
0.07	42.9
0.08	37.5
0.09	33.3
0.10	30.0
0.11	27.3
0.12	25.0
0.13	23.1
0.14	21.4
0.15	20.0
0.16	18.8
0.17	17.6
0.18	16.7
0.19	15.8
0.20	15.0
0.21	14.3
0.22	13.6
0.23	13.0
0.24	12.5
0.25	12.0
0.26	11.5
0.27	11.1
0.28	10.7
0.29	10.3
0.30	10.0
0.31	9.7
0.32	9.4
0.33	9.1
0.34	8.8
0.35	8.6

Figure 3--Theoretical relation between the critical minimum spread rate for active crown fire and crown bulk density in coniferous forest stands according to Van Wagner (1977). A tabulation of CBD and the corresponding R_o values in also given for the convenience of field users. Sample interpretation: The development of an active crown fire would not be possible at a CBD of 0.23 kg/m³ until the rate of spread after crowning exceed 13 m/min.

crown fire (m/min) and CBD = crown bulk density (kg/m^3). To compute R_o in either ch/hr or ft/min and CBD in lb/ft^3, the coefficient in equation (6) becomes 0.55861 or 0.61446 respectively, rather than 3.0. Note that the minimum spread rate required for active crowning increases as the bulk density of the crown fuel layer decreases (fig. 3). In the simplest case, the bulk density of the crown fuel layer in a coniferous forest stand is determined by dividing the foliage weight (kg/m^2 or lb/ft^2) by the average live crown length (m or ft). This assumes that only the conifer needles are involved in the crown fire propagation process and that they are uniformly distributed throughout the overstory canopy. The CBD determination is obviously somewhat more complex in immature and disease/insect-killed stands (Stocks 1987a, 1987b) since dead twigs and some branchwood may also become available for combustion. The development of an active crown fire does not occur in a single vertical lift but climbs progressively into the crown with its forward spread as illustrated, for example, by Geddes and Pfeiffer (1981, p. 10). Once the fire crowns, the flame front will be nearly vertical within the trunk space. Deflection by the wind field may begin within the crown fuel layer and be most pronounced above the tree crowns (see, for example, Van Wagner 1968, p. 16, figure 11). Active crowning will then continue provided that the rate of spread is fast enough to maintain a continuous flame in the crown phase (that is, when $R > R_o$) and the fire can transfer enough heat to the unburned tree crowns ahead to maintain continuous ignition.

Development of a truely independent crown fire on flat topography most certainly must require strong surface winds. This is necessary in order to achieve the direct flame contact and forward radiation heat transfer through the crown foliage, that is required to continue the propagation in a horizontal dimension, more or less independent of the surface fire energy output rate. In mountainous terrain, slope steepness no doubt compensates for the reduced wind flow; as for example, a 60% slope would result in about a 7-fold increase in rate of fire spread (see, for example, Lawson and others, 1985, p. 12, figure 6), and at least a corresponding increase in fire intensity compared to the same fuel and weather conditions on level terrain. Instances of independent crown fires have been reported (Rothermel and Mutch 1986). Sustained "runs" are undoubtedly a very rare event due to the natural variations in wind velocity, fuels and terrain. In certain forest cover types with very light surface fuel loads, such as the Ocala sand pine forests of north-central Florida, wildfires would appear to spread as an independent crown fire or not at all (Cooper 1973).

FIELD APPLICATION

On the basis of Van Wagner's (1977) crown fire model, a set of graphs and tables that relate I_o and L_o to LCBH and FMC were prepared following the present author's attendance at the S-590 Fire Behavior Officer (FBO) [now Fire Behavior Analyst or FBA] training course held at the USDA Forest Service's National Advanced Resource Technology Center (NARTC), Marana, Arizona, in December 1979 (Rothermel 1983, p. 107). One of the graphs was then included in Appendix F of Rothermel (1983, p. 142, figure F-1) but no adequate credit was given the original Van Wagner (1977) contribution. This graph was subsequently reproduced by Keown (1985) and included, along with the tables, in the FBO or FBA and Fire Behavior for Managers (FBM) Field References issued by NARTC since 1983. Tabulated versions of figures 1 and 2, for quick reference i the field, are appended to this paper (Appendix). These decision aids are based on equations (2) and (4). Some guidelines with respect to satisfying t five input requirements in the field application c Van Wagner's (1977) crown fire theory follow. Two worked-out examples of Van Wagner's (1977) model, based on data given in Quintilio and others (1977) and Newstead and Alexander (1983), are also summarized in table 1 for reference check purposes

Spread Rate (R) and Surface Fire Intensity (I_B)

The prediction of R and I_B would consider most of the known variables that influence fire behavic (i.e., air temperature, relative humidity, wind, fuel load, fuel moisture, slope, fuel arrangement, condition of herbaceous vegetation, etc.). There are basically five approaches to obtaining decent estimates of these two parameters:

- mathematical model such as the **BEHAVE** system similar method (Rothermel 1983; Andrews 1986)
- empirical-based system (Hough and Albini 1978 Lawson and others 1985);
- comparison with known wildfire case histories (Geddes and Pfeiffer 1981; Simard and others 1983; Rothermel and Mutch 1986) or experiment fire case studies (Quintilio and others 1977; Newstead and Alexander 1983; Stocks 1987a, 1987b; Alexander and De Groot 1988);
- recent on-site observations of fire behavior (e.g., Norum 1982); and/or
- experienced judgement.

Although the intensity of the surface fire requir to support a crown fire can be specified, the prediction of surface fire rate of spread and frontal intensity is, in fact, probably more difficult to predict than the level of crown fire behavior, given the most infinite variety of possible forest floor and understory fuel complex The rate of spread after crowning must exceed R_o, nearly so, in order to maintain an active crown fire. Van Wagner's (1977) model does not predict the spread rate after crowning has taken place. However, the recent work by Albini and Stocks (19 suggests that a physical model for the prediction crown fire rate of spread may soon be available i adaptation to field use. The effect of crowning the overall fire spread rate is accounted for directly in the rate of spread component equatior of the Canadian Forest Fire Behavior Prediction System (Lawson and others 1985). One possible approximation that could be applied to the variou methods of quantitative fire behavior prediction used in the U.S. (Andrews 1986), which are technically restricted to fire spread in surface fuels, is to fully or partially adjust the mid-f wind to the standard 6.1-m [or 20-ft] open wind speed value if crowning is anticipated on basis the predicted initial I_B (Anderson 1983; Simard others 1983).

Table 1--Application of Van Wagner's (1977) crown fire model to two contrasting situations

Item	Unit	Case A	Case B
Fuel type	-	Pine stand	Spruce stand
Predicted spread rate (R)	m/min	1.0	7.5
Predicted fire intensity (I)	kW/m	620	4230
Foliar moisture content (FMC)	%	117	109
Live crown base height (LCBH)	m	4.4	1.4
Crown bulk density (CBD)	kg/m^3	0.15	0.38
Critical surface intensity for crown combustion (I_o)	kW/m	1913	313
Critical minimum spread rate for active crown fire (R_o)	m/min	20.0	7.9
Type of fire	-	surface	active crown[1]

[1] Developing.

oliar Moisture Content (FMC)

seasonal cycle in the moisture content of oniferous tree foliage has been identified by everal investigators (table 2). Twenty to 40-ercentage point differences, within a range of bout 75 to 130%, have been documented. Diurnal ariation in FMC is also known to exist (Philpot 965), but is probably insignificant in terms of eal noticeable differences in fire behavior. At east in eastern and northern North America, a arked moisture decrease in the moisture content of + year-old needles, which constitutes the bulk of a ree's foliar dry weight, is evident in the spring ust before flushing of the new growth. As this new rowth continues to develop, the moisture content of he older foliage gradually increases. FMC is enerally highest in the late summer or early fall hen all the new growth has fully developed. imilar trends have also been reported in northern iberia (Kurbatskii 1972). The low spring moisture ontent of the 1+ year-old needles is felt to ontribute in a significant way to the probability f crown fire occurrences during the spring fire eason in many areas (Fuglem and Murphy 1980; Simard nd others 1983; Norum and Miller 1984), including he northern Rocky Mountains (Norum 1975), although ther fuel and weather factors are no doubt involved. e reason for this spring decrease in FMC is not tirely a reduction in the amount of water in the eedles but also, in part, a corresponding increase n starch content (Little 1970). This is not so ich a weather-caused phenomenon as a physiological ne; there are, however, field reports which suggest at occasionally severe drought conditions lead to normal moisture stress in trees growing on sandy, ll-drained sites. The exact timing of the normal pring dip" varies with elevation and latitude hilpot 1963; Fuglem and Murphy 1980). Significant fferences in the moisture content of coniferous liage between tree species and needle age do ist. There is substantial evidence to suggest at the annual trend probably does not vary greatly om year to year. The possibilities for obtaining reasonable FMC value are:

- general rules-of-thumb (typical value(s) for time of year and/or stage of plant growth) in a manner similar to the way in which estimation of moisture content in minor vegetation is handled by Rothermel (1983, p. 13, table II-2);
- on-site, near real-time measurement (Sackett 1980; Norum and Miller 1984);
- rely on published curves (table 2) or data (Brown 1978, p. 28-29) in the literature; or
- conduct independent study for species and locale of interest (Agee and Huff 1988).

Roussopoulos (1978a, 1978b), for instance, simply used a standard FMC value of 100% in his nomogram guide to the prediction of crown fires as "a common midsummer moisture content" in northeastern Minnesota.

Live Crown Base Height (LCBH)

The proportion of live tree crown does of course vary with tree height, stand density, etc. For example, in central British Columbia, Muraro (1971) found that the ratio of LCBH to tree height in lodgepole pine to be about 0.6:1. The distance from the ground surface to the base of the live crowns in a coniferous forest stand could be determined by:

- actual physical measurement;
- field observation ("guess-timate"); and/or
- infer from known relationship (for example, stand height and perhaps some measure of tree density) as illustrated in figure 4.

Examples of the latter method are also given in Anderson (1974), Cole and others (1982), Holdaway (1986), and Ritchie and Hann (1987).

Crown Bulk Density (CBD)

Determination of CBD requires: (1) crown foliage weight vs. diameter-at-breast height (dbh) relationship for the species of interest (Muraro 1971; Anderson 1974; Brown 1978; Roussopoulos 1978b; Freeman and others 1982); (2) number of stems per hectare (or acre) by dbh size class (based on stand exam or cruise data); and (3) the average stand crown length (this could of course be inferred from the mean stand height and mean live crown base height). There are basically two approaches available for determining crown bulk densities:

- calculate from stand inventory data and computer program, such as **HAZARD** (Puckett and others 1979) or related system (Radloff and others 1982) for a specific area.
- derive representative or stylized value(s) for various forest cover type/structure complexes (for example, "mature lodgepole pine") on a stand basis in a manner analogous to the way in which average individual tree crown bulk densities are quoted by Brown (1978, p. 25-28).

Note that bulk density does vary throughout the crown fuel layer as pointed out, for example, by Muraro (1971), Brown (1978) and others. Such a consideration could in fact result in a more refined estimate of the "effective" LCBH (Sando and Wick 1972; Roussopoulos 1978b).

Table 2--List of foliar moisture content studies conducted on conifer tree species in North America to date

No.	Reference(s)	Species[1]	Location
1.	Bunting, Stephen C.; Wright, Henry A.; Wallace, Walter H. 1983. Seasonal variation in the ignition time of redberry juniper. Journal of Range Management. 36(2): 169-171.	RJ	north-central Texas
2.	Chrosciewicz, Z. 1986. Foliar moisture content variations in four coniferous trees of central Alberta. Canadian Journal of Forest Research. 16(1): 157-162.	BS, WS, BF, JP	central Alberta
3.	Fingland, Randy D. 1987. Seasonal foliar moisture trends in Banff National Park. Vancouver, BC: University of British Columbia. 64 p. B.Sc.F. Thesis.	LP, WS	southwestern Alberta
4.	Fuglem, Peter L. 1979. Foliar moisture content of central Alberta conifers and its implication in crown fire occurrence. Edmonton, AB: University of Alberta. 148 p. M.Sc. Thesis. [*see* also Fuglem and Murphy 1980 in REFERENCES].	LP, BS, WS-ES	central Alberta
5.	Gary, Howard L. 1971. Seasonal and diurnal changes in moisture contents and water deficits of Engelmann needles. Botanical Gazette. 132(4): 327-332.	ES	north-central New Mexico
6.	Hough, W.A. 1973. Fuel and weather influences wildfires in sand pine forests. Res. Pap. SE-106. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 11 p.	SP	north-central Florida
7.	Jameson, Donald A. 1966. Diurnal and seasonal fluctuations in moisture content of pinyon and juniper. Res. Note RM-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.	UJ, AJ, OJ, P	central Arizona
8.	Johnson, Von J. 1966. Seasonal fluctuation in moisture content of pine foliage. Res. Note NC-11. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.	RP, JP	central Minnesota and Michigan
9.	Kiil, A.D. 1968. Changes in the physical characteristics and moisture content of pine and spruce-fir slash during the first five years after logging. Int. Rep. A-14. Edmonton, AB: Canada Department of Forestry and Rural Development, Forestry Branch, Forest Research Laboratory. 40 p.	LP, WS	west-central Alberta
10.	Kozlowski, Theodore T.; Clausen, J. Johanna. 1965. Changes in moisture contents and dry weights of buds and leaves of forest trees. Botanical Gazette. 126(1): 20-26.	WP, RP, BF, EH	northern Wisconsin
11.	Little, C.H.A. 1970. Seasonal changes in carbohydrate and moisture content in needles of balsam fir (Abies balsamea). Canadian Journal of Botany. 48(11): 2021-2028. [*see* also Little 1970 in REFERENCES].	BF	central New Brunswick
12.	Philpot, Charles W. 1963. Vegetation moisture trends in the central Sierra Nevada. Berkeley, CA: University of California. 53 p. M.Sc. Thesis. [*see* also Philpot 1963 in REFERENCES].	PP	central California
13.	Philpot, Charles W.; Mutch, Robert W. 1971. The seasonal trends in moisture content, ether extractives, and energy of ponderosa pine and Douglas-fir needles. Res. Pap. INT-112. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 21 p.	PP, DF	northwestern Montana
14.	Russell, R.N.; Turner, J.A. 1975. Foliar moisture content during bud swelling and needle flush in British Columbia. Bi-monthly Research Notes. Ottawa, ON: Canadian Forestry Service; 31(4): 24-25.	GF, WH, DF, NS	Vancouver Island, British Columbia
15.	Springer, E.A.; Van Wagner, C.E. 1984. The seasonal foliar moisture trend of black spruce at Kapuskasing, Ontario. Canadian Forestry Service Research Notes. 4(3): 39-42.	BS	northeastern Ontario
16.	Van Wagner, C.E. 1967. Seasonal variation in moisture content of eastern Canadian tree foliage and the possible effect on crown fires. Dep. Publ. No. 1204. Ottawa, ON: Canada Department of Forestry and Rural Development, Forestry Branch. 15 p.	WP, RP, JP, BF, WS	eastern Ontario
17.	Van Wagner, C.E. 1974. A spread index for crown fires in spring. Inf. Rep. PS-X-55. Chalk River, ON: Canadian Forestry Service, Petawawa Forest Experiment Station. 12 p.	RP	eastern Ontario

[1] WP = eastern white pine; PP = ponderosa pine; RP = red pine; JP = jack pine; LP = lodgepole pine; SP = sand pine; P = pinyon pine; WS = white spruce; ES = Engelmann spruce; BS = black spruce; NS = Norway spruce; EH = eastern hemlock; WH = western hemlock; BF = balsam fir; GF = grand fir; DF = Douglas- fir; RJ = redberry juniper; UJ = Utah juniper; AJ = alligator juniper; OJ = one-seeded juniper.

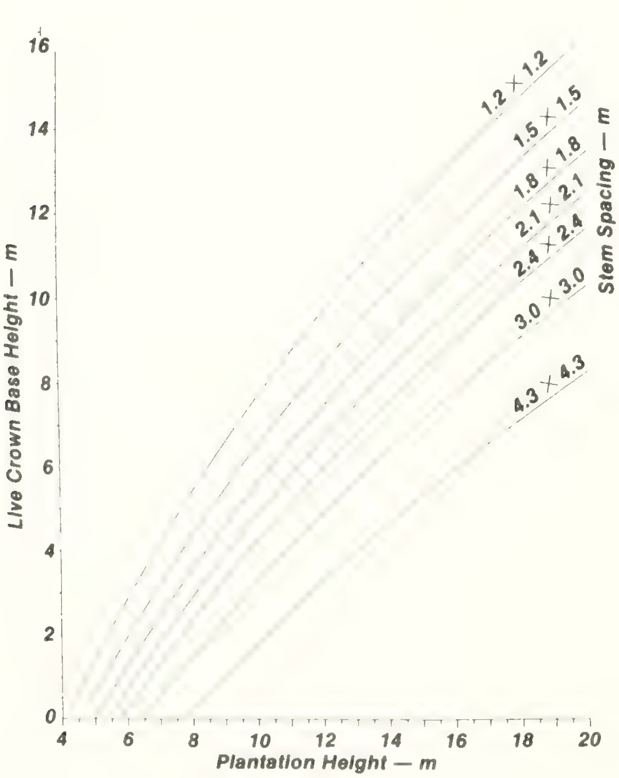


Figure 4--Relation between live crown base height and stand height in unthinned red pine plantations in eastern Ontario according to Stiell (1980).

I. Surface Fire Intensity (I_S) is predicted to be less than 10 kW/m.
  A. A firebrand has caused an ignition to occur **SELF-EXTINQUISHING FIRE; FAILS TO SPREAD.**
  B. Going fire **GROUND or SUBSURFACE FIRE.***

II. Surface Fire Intensity (I_S) is predicted to be greater than 10 kW/m but less or nearly equal to the Critical Surface Intensity for Crown Combustion (I_O).
  A. I_S is substantially less than I_O **SURFACE FIRE.**
  B. I_S is nearly equal to I_O **Developing PASSIVE CROWN FIRE.**

III. Surface Fire Intensity (I_S) is predicted to be equal to or greater than the Critical Surface Intensity for Crown Combustion (I_O).
  A. Rate of Fire Spread (R) is predicted to be less than or nearly equal to the Critical Minimum Spread Rate for Active Crown Fire (R_O).
    1. R is substantially less than R_O **PASSIVE CROWN FIRE.**
    2. R is nearly equal to R_O **Developing ACTIVE CROWN FIRE.**
  B. Rate of Fire Spread (R) is predicted to be equal to or greater than the Critical Minimum Spread Rate for Active Crown Fire (R_O).
    1. Forward heat transfer through the crown fuel layer relies upon surface fire phase **ACTIVE CROWN FIRE.**
    2. Energy requirements for the continued propagation through the crown fuel layer supplied entirely by the crown fire phase **INDEPENDENT CROWN FIRE.**

*Assuming there is a forest floor layer of significant depth and dryness.

Figure 5--A dichotomous key to a type of forest fire classification scheme based in part on Van Wagner's (1977) crown fire theory.

CLOSING REMARKS

Van Wagner's (1977) crown fire theory has received a fair amount of exposure in the wildland fire science literature (for example, Chandler and others 1983; Rothermel 1983; Pyne 1984) but implementation has been limited (see, for example, Roussopoulos 1978a, 1978b). His semi-physical model does remain largely untested. There certainly is a very strong need for further basic and applied research on crown fire modelling, especially with respect to spread rate prediction. Nevertheless, Van Wagner's approach, which is based on certain fundamental principles of fire physics, can be immediately applied to the systematic assessment of crown fire hazard (or at least supplement expert opinion) for use, at least on an interim basis, as an aid or tool in fire and fuel management planning today, particularly in even-aged conifer stands (fig. 5). For example, alternate strategies for manipulating the overstory stand structure and composition to limit the possibility and extent of crowning could be simulated (Sando and Wick 1972); this analysis could be coupled with a consideration of an area's "fire behavior climatology" (Salazar and Bradshaw 1986). Application of Van Wagner's model as a field guide and/or computer-assisted program for near real-time prediction of crown fire potential would, however, require some compilation and synthesizing of available information.

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REFERENCES

Abt, Robert; Kelly, David; Kuypers, Mike. 1987. The Florida Palm Coast Fire: an analysis of fire incidence and residence characteristics. Fire Technology. 23(3): 230-252.

Agee, J. K.; Huff, M. H. 1988. Foliar moisture of Pacific Northwest subalpine conifers. Northwest Science 62(2): 71.

Albini, Frank A.; Stocks, Brian J. 1986. Predicted and observed rates of spread of crown fires in immature jack pine. Combustion Science and Technology. 48(1+2): 65-76.

Alexander, Martin E. 1982. Calculating and interpreting forest fire intensities. Canadian Journal of Botany. 60(4): 349-357.

Alexander, M. E.; De Groot, W. J. 1988. Fire behavior in jack pine stands related to the Canadian Forest Fire Weather Index (FWI) System. Poster (with text). Edmonton, AB: Canadian Forestry Service, Northern Forestry Centre.

Anderson, Hal E. 1974. Forest fire retardant: transmission through a tree crown. Res. Pap. INT-153. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20 p.

Anderson, Hal E. 1983. Predicting wind-driven wild land fire size and shape. Res. Pap. INT-305. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 26 p.

Andrews, Patricia L. 1986. Methods for predicting fire behavior -- you do have a choice. Fire Management Notes. 47(2): 6-10.

Beale, John A.; Dieterich, John H. 1963. Crown fire problems in the Lake States. Wisconsin Conservation Bulletin. 28(1): 12-13.

Brown, Arthur A.; Davis, Kenneth, P. 1973. Forest Fire: control and use. 2nd ed. New York: McGraw Hill. 686 p.

Brown, James K. 1978. Weight and density of crowns of Rocky Mountain conifers. Res. Pap. INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 56 p.

Byram, George M. 1959. Combustion of forest fuels. In: Davis, Kenneth P., ed. Forest fire: control and use. New York: McGraw Hill: 61-89. [Chapter 3]

Chandler, C.; Cheney, P.; Thomas, P.; Trabaud, L.; Williams, D. 1983. Fire in forestry. Volume I: forest fire behavior and effects. New York: John Wiley & Sons. 450 p.

Cohen, W. B.; Omi, P. N.; Kaufmann, M. R. 1987. Water uptake of subalpine conifer branches during heating. In: Troendle, Charles A.; Kaufmann, M. R.; Hamre, R. H.; Winokur, Robert P., tech. coords. Management of subalpine forests: building on 50 years of research. Gen. Tech. Rep. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 207-210.

Cole, Dennis M.; Jensen, Chester E. 1982. Models for describing vertical development of lodgepole pine stands. Res. Pap. INT-292. Ogden, UT; U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Cooper, Robert W. 1973. Fire and sand pine. In: Sand pine symposium proceedings; 1972 December 5-7; Panama City Beach, FL. Gen. Tech. Rep. SE-2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 207-212.

Davis, Jim; Marker, John. 1987. The wildland/urban fire problem. Fire Command. 54(1): 26-27.

Fahnestock, George R. 1970. Two keys for appraising forest fire fuels. Res. Pap. PNW-99. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.

Freeman, Duane R.; Loomis, Robert M.; Roussopoulos, Peter J. 1982. Handbook for predicting slash weight in the Northeast. Gen. Tech. Rep. NC-75. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 23 p.

Fuglem, Peter L.; Murphy, Peter J. 1979. Flammability of jack pine crown foliage during spring. A research report submitted to the Alberta Forest Service. Unpublished report on file at: University of Alberta, Department of Forest Science, Edmonton, AB. 30 p.

Fuglem, Peter L.; Murphy, Peter J. 1980. Foliar moisture content and crown fires in Alberta conifers. ENR Rep. No. 158. Edmonton, AB: Alberta Energy and Natural Resources, Alberta Forest Service. 47 p.

Geddes, D. J.; Pfeiffer, E. R. 1981. The Caroline Forest Fire, 2nd February 1979. Bull. 26. Adelaide, SA: Woods and Forests Department of South Australia. 52 p.

Holdaway, Margaret R. 1986. Modeling tree crown ratio. The Forestry Chronicle. 62(5): 451-455.

Hough, W. A.; Albini, F. A. 1978. Predicting fire behavior in palmetto-gallberry fuel complexes. Res. Pap. SE-174. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 44 p.

Keown, Larry D. 1985. Fire behavior prediction techniques for park and wilderness fire planning. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings -- symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 162-167.

Kurbatskii, N. P. 1972. Seasonal variations in the moisture content of the needles of evergreen trees of the taiga. [In Russian.] Lesovedenie 1972(2): 44-50. [1978. Translation OOENV TR-1398. Ottawa, ON: Fisheries and Environment Canada Library. 14 p.]

Lawson, B. D.; Stocks, B. J.; Alexander, M. E.; Van Wagner, C. E. 1985. A system for predicting fire behavior in Canadian forests. In: Donoghue, Linda R.; Martin, Robert E., editors. Proceedings of the eighth conference on fire and forest meteorology; 1985 April 29-May 2; Detroit, MI. SAF Publ. 85-04. Bethesda, MD: Society of American Foresters: 6-16.

Little, C. H. A. 1970. Derivation of the springtime starch increase in balsam fir (*Abies balsamea*). Canadian Journal of Botany. 48(11): 1995-1999.

Merrill, D. F.; Alexander, M. E., editors. 1987. Glossary of forest fire management terms. 4th ed. Publ. NRCC No. 26516. Ottawa, ON: National Research Council Canada, Canadian Committee on Forest Fire Management. 91 p.

Muraro, S. J. 1971. The lodgepole pine fuel comple Inf. Rep. BC-X-53. Victoria, BC: Canadian Forestry Service, Forest Research Laboratory. 50 p.

Newstead, R. G.; Alexander, M. E. 1983. Short-term fire retardant effectiveness in a lowland black spruce fuel complex. Forestry Report. Edmonton, AB: Canadian Forestry Service, Northern Forest Research Centre; No. 28: 3-4.

Norum, Rodney A. 1975. Characteristics and effects of understory fires in western larch/Douglas-fi stands. Missoula, MT: University of Montana. 15 p. Ph.D. Dissertation.

Norum, Rodney A. 1982. Predicting wildfire behavio in black spruce forests in Alaska. Res. Note PNW-401. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

Norum, Rodney A.; Miller, Melaine. 1984. Measuring fuel moisture content in Alaska: standards and procedures. Gen. Tech. Rep. PNW-171. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 34 p.

Puckett, John V.; Johnston, Cameron M.; Albini, Frank A.; [and others]. 1979. Users' guide to debris prediction and hazard appraisal. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 37 p.

Philpot, C. W. 1963. The moisture content of ponderosa pine and whiteleaf manzanita foliage the central Sierra Nevada. Res. Note PSW-39. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 7 p.

Philpot, Charles W. 1965. Diurnal fluctuation in moisture content in ponderosa pine and whitele manzanita leaves. Res. Note PSW-67. Berkeley, U.S. Department of Agriculture, Forest Service Pacific Southwest Forest and Range Experiment Station. 7 p.

Pyne, Stephen J. 1984. Introduction to wildland fire; fire management in the United States. New York: John Wiley & Sons. 455 p.

Quintilio, D.; Fahnestock, G. R.; Dubé, D. E. 197 Fire behavior in upland jack pine: the Darwin Lake Project. Inf. Rep. NOR-X-174. Edmonton, Canadian Forestry Service, Northern Forest Research Centre. 49 p.

Radloff, David L.; Yancik, Richard F.; Walters, Kenneth G. 1982. User's guide to the national fuel appraisal process. [Unnumbered publicatio Fort Collins, CO: U.S. Department of Agricultu Forest Service, Rocky Mountain Forest and Rang Experiment Station. 41 p.

Ritchie, Martin W.; Hann, David W. 1987. Equation for predicting height to crown base for fourte tree species in southwest Oregon. Res. Pap. 50 Corvallis, OR: Oregon State University, Colleg of Forestry, Forest Research Laboratory. 14 p.

Rothermel, Richard C. 1983. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 161 p.

Rothermel, Richard C.; Mutch, Robert W. 1986. Behavior of the life-threatening Butte Fire: August 27-29, 1985. Fire Management Notes. 47(2):14-24.

Roussopoulos, Peter J. 1978a. A decision aid for wilderness fire prescriptions in the Boundary Waters Canoe Area. In: Preprint volume, fifth national conference on fire and forest meteorology; 1978 March 14-16; Atlantic City, NJ. Boston, MA: American Meteorological Society: 52-58.

Roussopoulos, Peter J. 1978b. An appraisal of upland forest fuels and potential fire behavior for a portion of the Boundary Waters Canoe Area. East Lansing, MI: Michigan State University. 166 p. Ph.D. Dissertation.

Sackett, Stephen S. 1980. An instrument for rapid, accurate, determination of fuel moisture content. Fire Management Notes. 41(2): 17-18.

Salazar, Lucy A.; Bradshaw, Larry S. 1986. Display and interpretation of fire behavior probabilities for long-term planning. Environmental Management. 10(3):393-402.

Sando, Rodney W.; Wick Charles H. 1972. A method of evaluating crown fuels in forest stands. Res. Pap. NC-84. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Simard, Albert J.; Haines, Donald A.; Blank, Richard W.; Frost, John S. 1983. The Mack Lake Fire. Gen. Tech. Rep. NC-83. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 36 p.

Stiell, W. M. 1980 [Letter to Martin E. Alexander]. March 4. 2 leaves. On file at: Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON; Project PI-12 files.

Stocks, B. J. 1987a. Fire potential in the spruce budworm-damaged forests of Ontario. The Forestry Chronicle. 63(1):8-14.

Van Wagner, C. E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7(1):23-24.

Van Wagner, C. E. 1983. Fire behaviour in northern conifer forests and shrublands. In: Wein, Ross W.; MacLean, David A., eds. SCOPE 18, the role of fire in northern circumpolar ecosystems. Chichester; New York: John Wiley & Sons: 65-80.

Webster, Joan Katherine. 1986. The complete Australian bushfire book. Melbourne: Thomas Nelson Australia. 269 p.

Wilson, A. A. G.; Ferguson, I. S. 1986. Predicting the probability of house survival during bushfires. Journal of Environmental Management. 23(3):259-270.

Stocks, B. J. 1987b. Fire behavior in immature jack pine. Canadian Journal of Forest Research. 17(1):80-86.

Van Wagner, C. E. 1968. Fire behaviour in a red pine plantation: field and laboratory evidence. Dep. Publ. No. 1229. Ottawa, ON: Canada Department of Forestry and Rural Development, Forestry Branch. 30 p.

A free-burning active crown fire in the boreal forest region of central Alberta (photo by author).

INTERNATIONAL SYSTEM (SI)-TO-ENGLISH UNIT CONVERSION FACTORS

If the SI units are:	Multiply by:	To obtain:	Inverse Factor
kilograms per cubic metre (kg/m^3)	0.062428	pounds per cubic foot (lb/ft^3)	16.018
kilograms per square metre (kg/m^2)	0.20482	pounds per square foot (lb/ft^2)	4.8824
kilojoules per kilogram (kJ/kg)	0.43021	Btu per pound (Btu/lb)	2.3244
kilowatts per metre (kW/m)	0.28909	Btu per second per foot (Btu/sec/ft)	3.4592
metres (m)	3.2808	feet (ft)	0.3048
metres per minute (m/min)	3.2808	feet per minute (ft/min)	0.3048
metres per minute (m/min)	2.9826	chains per hour (ch/hr)	0.33528

Note: All factors are given to five significant digits. If fewer, the value is exact. To convert English unit values to SI multiply by the inverse factor given in the right-hand column. A "Btu" is a British thermal unit.

APPENDIX: Critical Surface Intensity (I_o) and Flame Length (L_o) for Crown Combustion in Coniferous Forest Stands versus Live Crown Base Height (LCBH) and Foliar Moisture Content (FMC) based on Van Wagner (1977) and Byram (1959). Units: kilowatts per metre (kW/m) and metres (m).

LCBH (m)	FMC (% ODW basis)											
	75	80	85	90	95	100	105	110	115	120	125	130
	I_o (kW/m)											
0.5	42	45	49	52	56	60	64	68	72	76	80	84
1.0	118	128	138	148	159	169	180	191	203	214	226	238
1.5	217	235	253	272	291	311	331	351	372	393	415	437
2.0	335	362	390	419	449	479	510	541	573	606	639	673
2.5	468	506	545	586	630	669	712	756	801	847	893	941
3.0	615	665	717	770	824	880	936	994	1,053	1,113	1,174	1,236
3.5	775	838	903	970	1,038	1,108	1,180	1,253	1,327	1,403	1,480	1,558
4.0	946	1,024	1,104	1,185	1,269	1,354	1,441	1,530	1,621	1,714	1,808	1,904
4.5	1,129	1,222	1,317	1,414	1,514	1,616	1,720	1,826	1,934	2,045	2,157	2,271
5.0	1,323	1,431	1,542	1,656	1,773	1,892	2,014	2,139	2,266	2,395	2,526	2,660
5.5	1,526	1,651	1,780	1,911	2,046	2,183	2,324	2,467	2,614	2,763	2,915	3,069
6.0	1,739	1,881	2,028	2,177	2,331	2,488	2,648	2,811	2,978	3,148	3,321	3,497
6.5	1,961	2,121	2,286	2,455	2,628	2,805	2,986	3,170	3,358	3,550	3,745	3,943
7.0	2,191	2,371	2,555	2,744	2,937	3,135	3,337	3,543	3,753	3,967	4,185	4,407
7.5	2,430	2,629	2,834	3,043	3,258	3,477	3,701	3,929	4,162	4,400	4,641	4,887
8.0	2,677	2,897	3,122	3,352	3,589	3,830	4,077	4,328	4,585	4,847	5,113	5,384
8.5	2,932	3,172	3,419	3,672	3,930	4,195	4,465	4,741	5,022	5,308	5,600	5,897
9.0	3,194	3,456	3,725	4,000	4,282	4,570	4,865	5,165	5,471	5,783	6,101	6,425
9.5	3,464	3,748	4,040	4,338	4,644	4,956	5,276	5,601	5,933	6,272	6,617	6,968
10	3,741	4,048	4,363	4,685	5,015	5,353	5,697	6,049	6,408	6,774	7,146	7,525
11	4,316	4,670	5,033	5,405	5,786	6,175	6,573	6,979	7,393	7,815	8,244	8,681
12	4,918	5,321	5,735	6,159	6,593	7,036	7,490	7,952	8,424	8,904	9,394	9,892
13	5,545	6,000	6,467	6,945	7,434	7,934	8,445	8,966	9,498	10,040	10,592	11,153
14	6,197	6,706	7,227	7,761	8,308	8,867	9,438	10,021	10,615	11,221	11,837	12,465
15	6,873	7,437	8,015	8,607	9,214	9,834	10,467	11,113	11,772	12,444	13,128	13,824

LCBH (m)	FMC (% ODW basis)											
	75	80	85	90	95	100	105	110	115	120	125	130
	L_o (m)											
0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
1.0	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0
1.5	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3
2.0	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.5
2.5	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8
3.0	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.0
3.5	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.2	2.3
4.0	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4	2.5
4.5	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.6	2.7
5.0	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.6	2.7	2.8	2.8	2.9
5.5	2.3	2.3	2.4	2.5	2.6	2.7	2.7	2.8	2.9	3.0	3.0	3.1
6.0	2.4	2.5	2.6	2.7	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3
6.5	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4	3.5
7.0	2.7	2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7
7.5	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
8.0	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
8.5	3.0	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2
9.0	3.2	3.3	3.4	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.4
9.5	3.3	3.4	3.5	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5
10	3.4	3.5	3.7	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.6	4.7
11	3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.0
12	3.9	4.0	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.2	5.3
13	4.1	4.2	4.4	4.5	4.7	4.8	5.0	5.1	5.2	5.4	5.5	5.6
14	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.8	5.9
15	4.5	4.7	4.8	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1	6.2

THE ROLE OF THE PRIVATE FIRE CONSULTANT IN ASSESSING, REDUCING, AND MITIGATING WILDFIRE DANGER TO RURAL HOME SITES

Charles L. Bushey and Everett M. "Sonny" Stiger

ABSTRACT: Fire consultants in the private sector offer homeowners, neighborhoods, community planners and lawyers a diversity of services aimed at reducing wildfire hazard near residential structures and evaluating wildfire damage. The consultant has available a wide range of talents that can assess and reduce the potential for, or appraise and mitigate the damage from wildfires. These services are offered in conjunction with, but do not attempt to replace, those provided by existing fire suppression organizations.

INTRODUCTION

The private fire consultant is an important link in the quest to help homeowners and neighborhoods reduce their potential danger from catastrophic wildfire. Government and volunteer fire organizations have historically been restricted to fire suppression activities (structural and wildfire), public fire education, and internal inspection of buildings for fire hazard/safety and fire code violations. Very few publicly supported fire organizations have actively sought and maintained a role in the planning and implementation of reduced wildfire hazard to homes and neighborhoods. And in many respects, the roles of those fire suppression agencies have been legally restricted so as not to "interfere" with the expressed rights of the private homeowner to live in the surroundings that they enjoy. The fire agencies have had to work through the educational process to try and reach the growing numbers of individuals who build their homes in fire adapted and/or fire prone vegetation types. These public educational programs have had limited success in changing either the behavior or the desires of the home owner. The private fire consultant can help bridge the gap between mass education to a more personal level of homeowner education. The consultant can help the owner implement a fire hazard reduction program around their home or neighborhood.

PROFESSIONALS WITH EXTENSIVE SKILLS

Private fire consultants dealing with the wildland/residential home interface are still a relatively new profession which requires an unusal combination of talents. They must combine the acquired knowledges of fire ecology, wildfire suppression, and prescribed burning talents with the skills of the urban forester, lawn care specialist, community planner, landscape architect, business manager and public relations expert. Most individuals currently entering this field have had previous fire training and experience with either public or volunteer fire organizations.

RANGE OF SERVICES

The services which a private fire consultant can provide cover the entire range of helping the home owner. These duties usually do not include actual fire suppression services for structural or wildfire situations which are better handled by the organizations specifically equipped and trained for that type of job. The consultant however may closely interact with those fire suppression agencies. The services that our corporation provides, and which others may consider following are easily broken down into five general categories which together form a complete package of services to the interested land owner, community planner, or legal expert;

1. WILDFIRE DANGER ASSESSMENTS. A site visitation should be scheduled with the land owner or client to examine the potential wildfire hazard problems of the home or future residential property. It is during this visit that considerable education of the interested client can be accomplished on a one-to-one basis. Fire consultants should be able to provide a detailed description of the site fire ecology and help the client visualize the resultant vegetation (fuel) and wildlife successional changes which have likely occurred since the last fire or other major land management activity.

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C. L. Bushey is President of, and a Fire Ecologist/ Prescribed Fire Specialist with Montana Prescribed Fire Services, Inc., P.O. Box 2101, Missoula, MT 59806; E. M. "Sonny" Stiger is Vice President (Admin.) and a Prescribed Fire Specialist with Montana Prescribed Fire Services, Inc., P.O. Box 164, Wolf Creek, MT 59648.

A fuel load assessment of the property can be made to help illustrate to the client the amount of potential wildfire fuel that exists within the vicinity of their residence or property. Depending on the quality level desired and the final use of the fuel load assessment the fuel evaluation may be completed in an intensive (quantitative fuel inventory), or in a less intensive (photo guide, general NFFL or NFDRS fuel model) manner.

After the fuel load assessment the fire consultant can provide the client with a potential wildfire behavior evaluation and a "Fire Potential Rating" for the site using weather conditions which would represent an average bad day during the wildfire season in the general vicinity. The wildfire behavior evaluation should be site specific for the fuel conditions that surrounds the home. Fire behavior evaluations may be developed for both the untreated fuel conditions and the consultant recommended fuel levels after implementation of a wildfire hazard reduction program. The predicted wildfire behavior calculations will illustrate to the client the amount of heat, flame length, and other fire behavior predictions the site and residents could possibly experience in the event of a wildfire.

The potential fire behavior the specific site could experience then needs to be explained in layman terms to the client. The discussion should include the probable impacts of a wildfire under those conditions to site structures, vegetation, soil, wildlife habitat, and overall site esthetics. The fire consultant should indicate the potential danger from surrounding lands not owned by the individual currently interested in your services. Either the fire consultant or the land owner may approach these neighbors, however best results are usually attained with neighbors talking to neighbors.

2. PLANNING. The consultant should develop for the homeowner, or preferably for a residential subdivision, a detailed series of steps to formulate a time schedule for reducing their wildfire hazard. These steps need to be within the land use goals and constraints of the owner or neighborhood. A time schedule for implementation of each step is essential to continually reenforce, and eventually attain the goal of reduced wildfire hazard. Another reason for the time schedule is that many steps to reduce wildfire hazard may best be accomplished only during favorable weather or a specific phenological period of the year.

The private fire consultant should be available to consult with community planners, local fire departments and residential developers in designing residences and neighborhoods for reduced wildfire hazard. This cooperation is best accomplished long before construction begins. This work should not only emphasize the need to reduce wildfire hazard around the community through fuel manipulation and increased wildfire resistant structures, but also to increase the ability of fire suppression forces to access and defend the neighborhood while area residents are safely being evacuated. The community should develop with the consultant a workable plan ready to implement their fire fighting and emergency forces in the event a worse case scenario should develop. The plan should include cooperation wit other structural and wildland fire suppression forces for an organized plan of attack and support. Additional items which community planners may need help with include developing sensible zoning regulations for their rural/wildland interface. Also subdivisions with "Owners Covenants" may need help with their local regulations in dealing with the topic of wildfire hazard reduction.

3. PROTECTION. The complete private fire consulting service should be able to provide professional, insured or bonded services to implement the plan for the reduction in residential wildfire danger which they have developed. This must be accomplished in an esthetically pleasing manner that fulfills the goals of the home owner. These services may include, but not necessarily be limited to:

a) tree and brush thinning and removal,
b) tree pruning,
c) debris and litter removal,
d) prescribed burning,
e) understory seeding and wildlife plantings,
f) the selective application of chemical herbicides or growth retardents.

These various services should be available if desired, to the client on a long-term contractual basis.

4. WILDFIRE DAMAGE APPRAISAL. As long as man and nature interact there will be wildfires which can potentially damage resources considered valuable by man. Fire consultants need to be available to evaluate fire effects as to their potential benefits or harm to both vegetation and wildlife. This skill requires a knowledge of fir ecology and fire behavior frequently not taught t the average forester, range conservationist or wildlife biologist. It may be periodically necessary for the consultant to develop a cost, o other quantitative assessment of changes in important resource values induced by a wildfire.

Alleged changes in resource values induced by wildfire frequently lead to litigation for reimbursement. The private fire consultant shoul be knowledgeable enough and available to provide "Expert Witness" testimony in legal conflicts concerning fire effects, fire behavior, fire weather, wildfire suppression and prescribed fire planning and activities.

5. WILDFIRE DAMAGE MITIGATION. In conjunction with the services provided for reducing wildfire hazard around homes, the privat fire consultant should be able to apply their skills to the development and implemention of ecologically sound range and forest rehabitation programs on wildfire damaged lands.

CONCLUSION

In whole or part, the services which the private fire consultant can offer provides an important source of expertise for the concerned homeowner, homeowner associations, community planners, and legal professionals confronted with a topic (wildfire) they are unfamiliar with. It is our hope that in the future the private fire consultant can point with pride to completed projects that have saved lives and homes from wildfire.

THE WILDLAND-URBAN INTERFACE: WHAT IT IS, WHERE IT IS AND ITS FIRE MANAGEMENT PROBLEMS

James B. Davis

ABSTRACT: Fire managers across the nation are confronting the rapidly developing problem of people moving into wildland areas, increasing what has been termed the wildland-urban interface. To manage more effectively and plan for this situation, fire managers should analyze the problem as three types of interface areas, each with its own unique set of demographic factors, local land use, and fire protection problems.

INTRODUCTION

Almost all persons involved in wildland fire control are familiar with the term "wildland-urban interface." They probably have seen the growing problem in their communities, that is, a dramatic increase during the past 10 to 15 years in the number of people leaving cities and moving into the wildlands (Davis 1986). When we take a close look at where the interface areas are and how they are affected by population trends, we find a very complex situation.

A ranger on a National Forest in Michigan may view the problem as one of balancing the protection of the natural resources with the political expediency of giving equal or better protection to summer and vacation homes for which the USDA Forest Service has no legal responsibility.

A State forester in New Jersey may lose sleep over the suburban sprawl into the fire prone Pine Barrens. In addition, the forester may see the organization growing at a slower rate than the protection problem and feel the organization will soon be at the lower threshold of suppression effectiveness.

A California fire chief may worry about large accumulations of flammable native vegetation, steep slopes, and narrow winding roads well within the boundaries of what most of us would consider a metropolitan area.

Not only are the vegetation and structural "fuel" problems variable and complex in these different interfaces, but the location and movement of people are different from one part of the nation to another, and population trends change rapidly over time (Bogue 1985).

The problem is further complicated by a patchwork of legal and organizational requirements and constraints. For example, some States have specific legal requirements for the protection of structures in the wildland. Others have no legal responsibility and neither train their personnel, nor purchase the specialized equipment needed for structure protection. On the other hand, many agencies with thousands of acres of wildland within their jurisdictions may be unprepared to effectively fight a wildland fire.

This paper shows how demography—the study of the characteristics of human populations including size, growth, density, and distribution—can be a useful tool for analyzing and predicting fire management problems.

WHERE IS THE WILDLAND-URBAN INTERFACE?

The American people, it seems, are as dynamic and shifting as the desert sand. For most of our history as a nation, there has been a flow of people from rural areas into cities (Herbers 1986). Then, during the 1970's, this traditional pattern changed. Americans left the cities in record numbers to live in small towns and rural areas (Kloppenburg 1983). For the first time since the industrial revolution, the population growth rate outside the nation's metropolitan areas was more rapid than within (fig. 1).

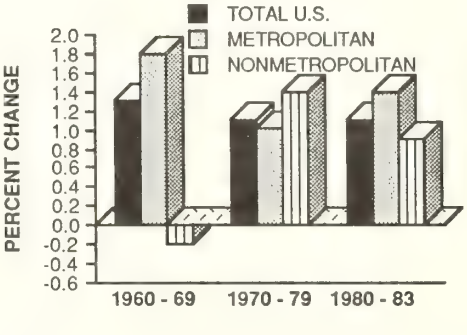

Figure 1—Average annual percent population change by decade (Sternlieb and others 1982).

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, California.

Now there seems to be another change (Bradshaw 1987). Census information from the first half of the 1980's show that urban areas are growing again—but for different reasons. Areas that were once classified as rural are rapidly achieving sufficient population to be reclassified as urban. Typical areas are the Los Angeles Basin and the corridors between Boston and New York, and between New Jersey and Washington D.C. (Engels and Forstall 1985).

If we look at these trends in more detail from a geographic standpoint, we find some important regional relationships. Americans are more dispersed across the country than ever before. A majority of people now live in the the South and the West (Long and DeAre 1983). All but one of the top 10 growth States of the 1970's were west of the Mississippi River. In 19 States the nonmetropolitan areas are still growing at a faster rate than the metropolitan areas. Only in the South is the metropolitan population growing at a much faster rate than is the nonmetropolitan population (table 1).

These changing patterns of population distribution have important implications on how we fight wildland fires today and how we must plan to fight them in the future. To understand the implications of these patterns, we first need to define what is meant by the wildland-urban interface. As implied earlier, the term can mean different things to different people.

WHAT IS THE WILDLAND-URBAN INTERFACE?

The concept of three types of wildland-urban interface areas was first suggested by Charles W. Philpot, Associate Deputy Chief for Research, USDA Forest Service, at a wildland-urban interface meeting in Boston in 1986.

Three general types of interface have been identified (NW/UFPC 1987):

- Classic Interface—where city boundaries and suburbs press against wildland vegetation.
- Mixed Interface—where homes and other structures are intermixed with wildland vegetation.
- Occluded Interface—where islands of wildland vegetation occur inside a metropolitan area.

The Classic Interface

By far the greatest number of people live in (and are moving into) the classic interface (fig. 2). This is the area where homes, especially new subdivisions, press against the wildland area. Frequently, vast, adjacent wooded areas can propagate a massive flame front during a wildfire, and numerous homes are put at risk by a single

Table 1—Percent change in state population growth: 1980-83 (Engels and Forstall 1985)

State	Metropolitan	Nonmetropolitan
Northeast		
Maine	1.4	2.2
New Hampshire	5.2	2.4
Vermont	3.1	2.6
Massachusetts	0.3	5.2
Rhode Island	0.6	3.5
Connecticut	0.9	2.2
New York	0.6	0.7
New Jersey	1.4	—
Pennsylvania	0.2	0.7
Midwest		
Ohio	-0.5	-0.2
Indiana	0.1	-0.8
Illinois	0.8	-0.9
Michigan	-2.5	-0.3
Wisconsin	0.7	1.5
Minnesota	2.6	0.0
Iowa	0.6	-1.0
Missouri	1.1	1.0
North Dakota	3.7	4.6
South Dakota	4.4	0.7
Nebraska	3.5	0.3
Kansas	3.9	1.3
South		
Delaware	1.5	2.9
Maryland	2.1	1.6
Virginia	4.9	1.4
West Virginia	-0.6	1.6
North Carolina	3.8	2.9
South Carolina	4.8	4.1
Georgia	6.2	2.8
Florida	9.4	11.6
Kentucky	0.2	2.5
Tennessee	2.1	1.9
Alabama	2.0	1.1
Mississippi	4.6	1.9
Arkansas	2.1	1.6
Louisiana	5.9	4.7
Oklahoma	10.3	7.4
Texas	11.3	7.3
West		
Montana	4.6	3.6
Idaho	6.5	4.4
Wyoming	7.4	9.9
Colorado	8.5	9.1
New Mexico	6.1	8.5
Arizona	9.6	5.3
Utah	10.1	13.3
Nevada	11.2	11.9
Washington	4.5	2.3
Oregon	1.3	0.6
California	6.2	8.7
Alaska	21.1	17.8
Hawaii	4.8	11.0

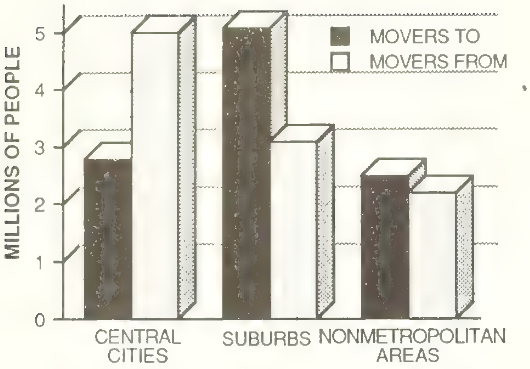

Figure 2—Declining cities and growing suburbs: while the nonmetropolitan areas continue to grow, it is the suburbs that attract most movers. This population growth affects both the classic and occluded interfaces (U.S. Bureau of the Census).

fire sometimes overwhelming fire protection forces and water supplies. The classic interface is also where the greatest structural fire loss occurred in the past and is expected to occur in the future.

Once considered only a southern California problem, now no region of the nation can be expected to escape the problems of the classic interface. In May 1985, 99 homes in Florida's Palm Coast Development were destroyed within a few hours (Abt and others 1987). In 1987, a 900-acre brush fire near Spokane, Washington, destroyed 24 homes and damaged at least 30 others. A New Jersey fire warden predicted that should a fire situation develop similar to the one that occurred in that state in 1963, structural fire loss could amount to 1,500 homes with damage in excess of 100 million dollars (Hughes 1987a, b).

There are at least two reasons why the classic interface is growing so rapidly. The first is that suburbs closest to the central cities are becoming more like the cities themselves with many of the cities' traditional problems (Schapiro 1980). New suburbs are spreading farther from the city center, attracting today's younger families. From a demographic standpoint, the World War II "baby boom" is now today's young-to-middle-aged adults with families. By past standards this is a relatively large and affluent group (Sternlieb and others 1982).

When Americans can afford to move out of the cities or older inner suburbs they frequently do (Newitt 1983). The Washington D.C. area is an example of the relationship between moderate wealth and the demand for space. New subdivisions are spreading across the rural, frequently flammable, Virginia and Maryland countryside—some of them as much as 50 miles or more from downtown Washington D.C.

The second reason for the rapid growth of the classic interface is the development of "super cities." One of the definitions used by the Census Bureau is this one of an urbanized area: a city with a population of 50,000 or more together with all the contiguous built-up land that has a population density of at least 1,000 people per square mile. Much of the increase in "urban" growth during the 1980's has been a rapid change from rural to urban status for many communities. Usually this takes place near—often between—major cities resulting in what has been called the "closing of the megalopolis." Between 1970 and 1980 these areas grew at a rate 10 times that of the inner city (Long and DeAre 1983).

The classic interface is where the built up quality of the subdivision may give a false sense of security. Paved streets, fire hydrants, and green lawns may give the impression that there is no fire threat from nearby wildands. Yet as shown in many fires, embers and burning shakes and shingles flying through the air have ignited roofs a half mile or more from the nearest wildland vegetation.

The Mixed Interface

The mixed interface (sometimes called intermix) usually consists of homes or other buildings scattered throughout the wildland area. Small and occasionally medium sized subdivisions may also be included. Typical are summer homes, recreation homes, ranches, and farms in a wildland setting. Usually these isolated structures are surrounded by large areas of vegetation-covered land. In a fire, the structures are very hard to protect because of the large area that may be burning, but relatively few homes may be at risk.

While these areas are not growing as rapidly in many cases as they once were, the growth rate and infrastructure problems involving schools, roads, water and sewage systems, and fire protection are still formidable. For example, between 1970 and 1978 the five California counties with the highest percentage growth rate in population were in the wildlands of the Sierra Nevada (Irwin 1987a, Sweeney 1979). The population of one of these counties (Alpine) jumped 107 percent between 1970 and 1978. Population growth in the Blue Ridge Mountains of Virginia has been even more rapid. The homes exposed to wildfire loss in portions of the Blue Ridge increased more than 400 percent between 1979 and 1984 (fig. 3).

Frequently the people moving into the mixed interface bring with them a perception of forestry that often clashes with ecological reality. They are much more concerned with their conception of "forest preservation" than with the forester's or fire manager's idea of forest management and conservation. There is often a desire by both home owners and county planning departments to provide open space areas. One California planning commissioner stated, "We regularly review two or three proposals a month that contain either open space or wildlife corridor zoning designations."

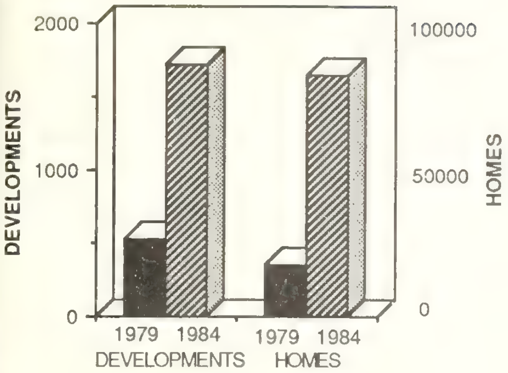

Figure 3—The increase in the number of homes and subdivisions exposed to fire loss in Virginia between 1979 and 1984 (Graff 1986).

Past county (Tuolumne) policy has been to word the conditions of the zoning so that no vegetation will be removed (Irwin 1987b). However, relatively few California counties include fire concerns or fuel management in their open space zoning, allowing fuel corridors to develop that may run through residential developments.

In addition to the newly arriving residents' vulnerability to wildfire, there is the ecological impact on the forest itself (Rice 1987). People try to retain the forested quality of the site not realizing that it is still subject to fire, insects, and disease as before, but is threatened now by the effects of urbanization as well. The root systems of many trees are cut by road construction, compacted, or paved over. Native trees may be adversely affected by watering of lawns and nonnative shrubbery and in some cases so weakened that they are readily attacked by insect pests. Near Lake Arrowhead, in southern California, 50 percent of the pines are damaged by such "people pressure" (Walt 1986). Leaving old declining trees, the weakening or killing of others, and adding houses and other buildings to the list of combustibles in the forest causes a growing load of fuel.

The people moving into the mixed interface are a varied group. In one locality the newcomers were found to include five categories (Herbers 1986, Sweeney 1979):

- Commuters, more and more of whom are willing to travel long distances from a mountain setting to jobs in urban areas.
- The retired, who want to trade-in urban problems such as crime and smog for a remote and more peaceful home in the mountains or foothills.
- Younger dropouts from the urban rat race. Many of these with families want to raise their children in a simpler, less pressured lifestyle, away from the problems of city schools and rush hour traffic jams.
- Older more successful corporate executives who wish to exchange long hours spent in often well-paying jobs for even longer hours spent launching their own small businesses.
- The poor, who may find that it is the only place they can afford to live. In many cases a home (or mobile home) in the wildland is far less expensive than similar accommodations in more developed places.

Many of these newcomers possess at least two characteristics in common: they are very aware of their environment; and they are very much interested in getting involved in what has been called "stewardship of the land." Every Forest Service manager responsible for a forest plan knows well the extent of this wish for involvement and participation.

Complicating the fire problems in the mixed interface is that frequently the only fire protection available is either forestry agencies that are budgeted, equipped, and trained only for wildland firefighting, or poorly staffed and poorly equipped volunteers. Fire managers must make the tough decisions about sacrificing natural resources to protect homes and other structures, usually with personnel and equipment not particularly suitable for the job. This conflict leads to a mismatch between property owner's fire protection expectations and fire agency protection strategies, which frequently leads to lack of trust, and—on occasion—to litigation.

The Occluded Interface

An occluded interface is characterized by isolated (either small or large) areas of wildland within an urban area. An example is an undeveloped or primitive city park surrounded by homes trying to preserve some contact with a natural setting.

The same demographic trends affecting the classic interface also influence this interface. As the megalopolis closes to make a super city, islands of undeveloped land get left behind. In some cases these are specifically set aside as parks. In other cases they may be steep difficult places that are unsuitable as building sites. The occluded interface may even occur in portions of inner cities as parks or as intractable terrain left behind by developers.

Many homes and other buildings may be at risk, but the relatively small wildland areas are not as subject to large scale fire. This does not mean that fires cannot be deadly. In 1985 three home owners died when an 8-acre fire, well within the Los Angeles metropolitan area, swept up a steep slope and overran their homes. Fires in the occluded interface can be dangerous and difficult to fight because of steep difficult terrain and limitations on suppression methods due to the proximity of structures. The Los Angeles County Griffith Park Fire of 1933--a typical occluded interface fire--was the most tragic in the nation's history from the standpoint of firefighter casualties, with 25 killed and another 128 injured (Wilson 1977).

The Griffith Park Fire is possibly the nation's worst fire of any type--forest or structural--based on total firefighter casualties. More total lives, however, have been lost on several large historical fires. These include the 1871 Peshtigo Fire in Wisconsin where 1,500 people perished, the 1894 Hinkley Fire in Minnesota with 418 fatalities, and the 1881 Michigan Fire in which 169 people died (Davis 1959).

IMPLICATIONS FOR FIRE MANAGEMENT AND RESEARCH

The wildland-urban interface is very complex from the standpoint of fire planning and management. Each type of interface--mixed, classic, and occluded--has its unique demographic characteristics and fire protection problems.

Demographic analysis can help managers to (1) identify each type of interface, (2) identify the occupants of each interface, and (3) track population trends affecting the interfaces.

By examining and understanding how these future population trends will affect fire protection tactics and strategy in each of the interfaces, managers should be able to plan ahead--to be proactive rather than reactive in relations with the public and its leaders in managing the wildland-urban interface fire problem.

A recent survey of California fire managers assessed the research needs of the interface fire problem. The highest priority for research was for an effective method to communicate with the public, and particularly, public policy leaders before there was commitment to a course of land development that might be contrary to good fire protection (Davis 1987).

REFERENCES

Abt, Robert; Kelly, David; Kuypers, Mike. 1987. The Florida Palm Coast fire: an analysis of fire incidence and residence characteristics. Fire Technology. 23(3): 230-252.

Bogue, Ronald J. 1985. The population of the United States, historical trends and future projections. New York: The Free Press. 350 p.

Bradshaw, Ted K. 1987. The intrusion of human population into forest and range lands of California. In: Proceedings of the Symposium on Wildland Fire 2000; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 15-21.

Davis, James B. 1986. Danger zone: the wildland/urban interface. Fire Management Notes. 47(3): 3-5.

Davis, James B. 1987. Assessing subjective preferences for future fire research. In: Proceedings of the Symposium on Wildland Fire 2000; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 121-127.

Davis, Kenneth P. 1959. Forest fire control and use. New York: McGraw Hill. 584 p.

Engels, Richard A.; Forstall, Richard L. 1985. Metropolitan areas dominate growth again. American Demographics. 7(4): 23-39.

Graff, John. 1986. [Personal communication]. Riverside, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Herbers, John. 1986. The new heartland. Times Books, New York: Random House. 228 p.

Hughes, Joseph B. 1987a. Development in the Pine Barrens: a design for disaster. Fire Management Notes. 47(4): 24-27.

Hughes, Joseph B. 1987b. New Jersey, April 1963: Can it happen again? Fire Management Notes. 48(1): 3-6.

Irwin, Robert L. 1987a: Local planning considerations for the wildland-structural intermix in the year 2000. In: Proceedings of the Symposium on Wildland Fire 2000; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 38-46.

Irwin, Robert L. 1987b. [Personal communication]. Riverside, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Kloppenburg, Jack. 1983. The demand for land. American Demographics. 5(1): 34-37.

Long, Larry; DeAre, Diana. 1983. The slowing of urbanization in the U.S. Scientific American. 249(1): 33-41.

Newitt, Jane. 1983. Behind the big-city blues. American Demographics. 5(6): 27-39.

NW/UFPC. Wildfire strikes home. 1987. Report of the National Wildland/Urban Fire Protection Conference. Quincy, MA: National Fire Protection Association. 90 p.

Rice, Carol L. 1987. What will the wildlands be like in the year 2000...future perfect or future imperfect? In: Proceedings of the Symposium on Wildland Fire 2000; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 26-31.

Schapiro, Morton Owen. 1980. Filling up America: an economic-demographic model of population growth and distribution in the nineteenth-century United States. Greenwich, CT: JAI Press Inc. 425 p.

Sternlieb, George; Hughes James W.; Hughes, Connie O. 1982. Demographic trends and economic reality: planning and marketing in the '80s. Center for Urban Policy Research, State University of New Jersey. 154 p.

Sweeney, Joan. 1979. Sierra lure--urban dropouts bring urban problems. Los Angeles Times. March 25.

U.S. Bureau of the Census. 1982. Geographical mobility: March 1980 to March 1981. Current Population Reports, Series P-20, No. 377. 143 p.

Walt, Harold R. 1986. Problems in the urbanized forest. The Christian Science Monitor. March 17.

Wilson, Carl C. 1977. Fatal and near fatal forest fires: the common denominators. International Fire Chief. 43(9): 9-15.

APPLICATION OF FIRE DANGER RATING TO THE WILDLAND/URBAN FIRE PROBLEM:

A CASE STUDY OF THE NISBET PROVINCIAL FOREST, SASKATCHEWAN

William J. De Groot

ABSTRACT: Fire potential is quantified in terms of fire intensity, rate of fire spread, and fire growth for a wildland/urban interface area in central Saskatchewan based on historical weather records and the Canadian Forest Fire Danger Rating System (CFFDRS). Conditions conducive to fast spreading (>22 m/min), high intensity (>4000 kW/m) fires with rapid growth (>55 ha in one hour) occur on a regular basis during the fire season. The CFFDRS can indirectly be used to communicate this wildland/urban fire problem to the public.

INTRODUCTION

The problem of fire in the wildland/urban interface has become increasingly more apparent through the many recent workshops, symposiums and conferences dealing with this topic, as well as through home and life-threatening occurrences. Quantification of this fire problem through research and technology transfer has been described as part of the solution (Gale and Cortner 1987; Laughlin and Page 1987). Although the exact role that the research community will play has not been specifically identified, there undoubtedly are opportunities for application of current available research through the technology transfer process.

Research into fire danger rating and fire behavior has a long history (Brown and Davis 1973) and products from this research can be used to quantify the wildland fire aspects of the wildland/urban fire problem. This includes rate of fire spread, area burned, fireline intensity, spotting, and crowning potential. These forest fire management terms follow those defined by Merrill and Alexander (1987). For those concerned about protecting people and homes from wildfire, important information would include fire intensity, rate of fire spread and area burned. This paper deals solely with quantifying fire potential in these terms. This type of fire behavior information can be used to develop a means of communicating the wildland/urban fire problem to the general public. Using the wildland/urban area of the Nisbet Provincial Forest as an example, fire potential (measured in terms of rate of fire spread, fire intensity and area burned) was quantified using the Canadian Forest Fire Danger Rating System (CFFDRS) (Canadian Forestry Service, 1987).

THE WILDLAND/URBAN FIRE PROBLEM

The Nisbet Provincial Forest is located in central Saskatchewan, just north of Prince Albert (fig. 1). Mean daily temperatures in this area during January and July are -21.5°C (-6.7°F) and 17.4°C (63.3°F). The mean first snow-free and snow-cover dates are April 22 and October 30. Mean annual precipitation is 40.1 cm (15.8 in.), including 125.0 cm (49.2 in.) of snowfall. The critical area of the Forest (fig. 2) is 26 366 ha (65 153 ac) and has a residential population of over 1 500 either within, or directly adjacent to, its boundaries (Saskatchewan Parks and Renewable Resources 1984). Commercial, institutional and industrial values are also prevalent in the Forest.

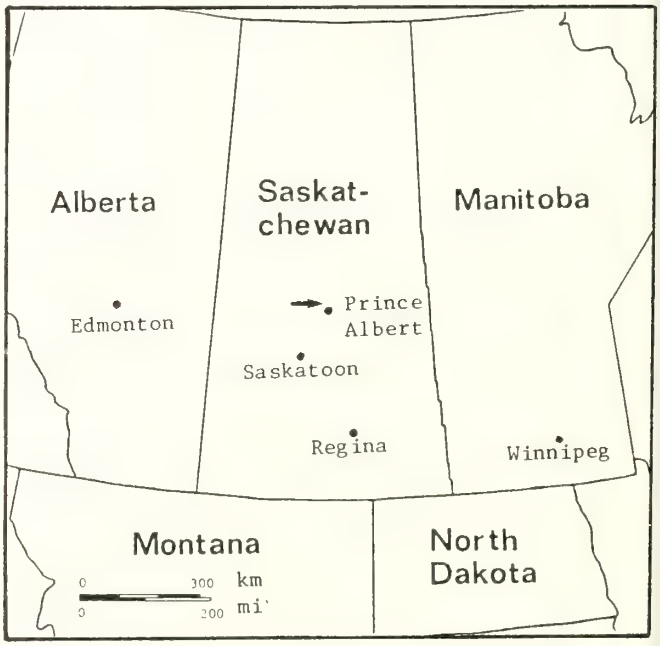

Figure 1--Geographical location of the Nisbet Provincial Forest (arrow).

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

William J. De Groot is Fire Research Officer, Saskatchewan District Office, Canadian Forestry Service, Prince Albert, SK, Canada.

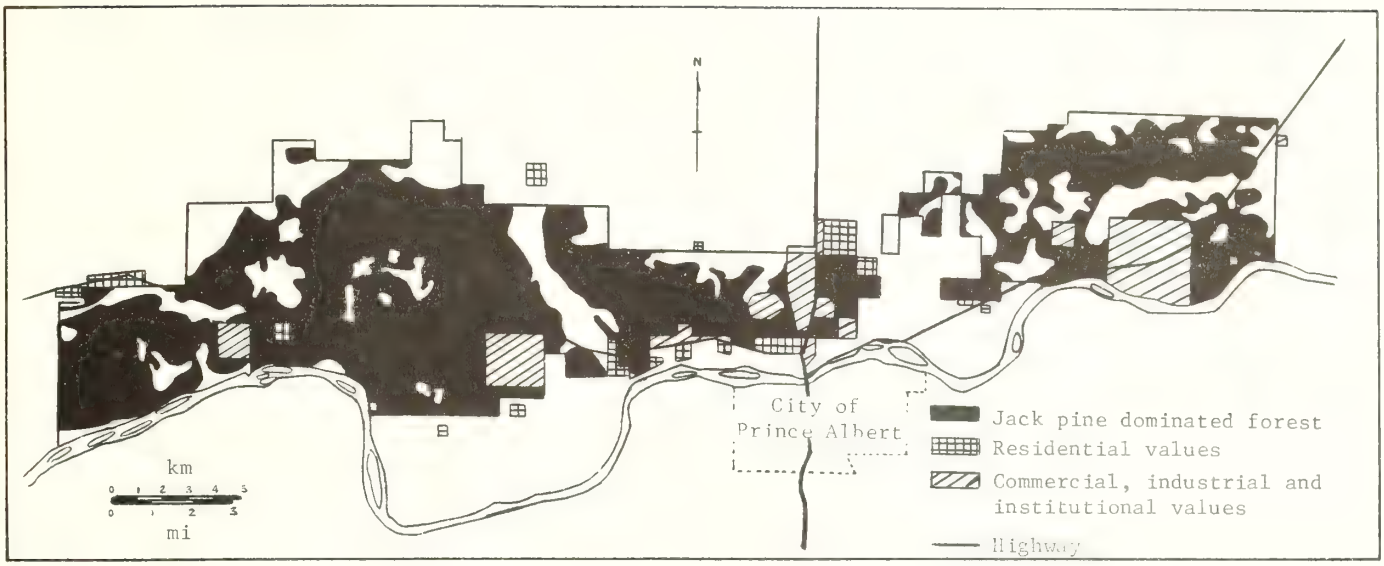
N
City of
Prince Albert
Jack pine dominated forest
Residential values
Commercial, industrial and institutional values
Highway
km
0 1 2 3 4 5
0 1 2 3
mi

Figure 2--Critical areas within the Nisbet Provincial Forest (after Saskatchewan Parks and Renewable Resources 1984).

The Nisbet Forest is a high-use recreational area, primarily because of the proximity to the City of Prince Albert. Ninety-nine percent of all fires are man-caused, usually the result of abandoned campfires. In 1987, 95 fires required suppression action in the Forest.

Although the Nisbet Forest is located in the mixedwood section of the southern boreal ecoregion (Kabzems and others 1986), jack pine (Pinus banksiana Lamb.) dominates the generally moisture deficient sandy soils of the area. Much of the Forest is heavily infected with dwarf mistletoe (Arceuthobium americanum Nutt. ex Engelm.). The understory is typically reindeer moss (Cladonia sp.), bearberry (Arctostaphylos uva-ursi (L.) Spreng.), dry ground cranberry (Vaccinium vitis-idaea L. var. minus Lodd.), and feather moss (Pleurozium schreberi (BSG.) Mitt.). The topography varies from gently undulating to strongly rolling.

The combination of significant values-at-risk, extensive recreational use with resulting high fire incidence, and the presence of a hazardous fuel type on droughty sites creates a potentially serious fire problem in this wildland/urban interface area.

ANALYZING THE HISTORICAL FIRE POTENTIAL

The only additional element needed to create a dangerous wildfire situation in the Nisbet Forest is the appropriate fire weather. The Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1984; Van Wagner 1987) is a sub-system of the CFFDRS, and uses consecutive daily noon weather observations to gauge the relative fire potential in a standard fuel type on level terrain. Harrington and others (1983) calculated the component values of the FWI System using meteorological data supplied by the Atmospheric Environment Service of Environment Canada for the period 1953-80. Summaries for the 28 years of FWI System values for the Prince Albert airport meteorological station (Harrington and others 1983) were then applied to the Canadian Forest Fire Behavior Prediction (FBP) System (Alexander and others 1984), another sub-system of the CFFDRS, to quantify frontal fire intensity (Alexander 1982) and rate of fire spread potential on a historical basis.

The fire intensity levels shown in figure 3 follow those designated on the intensity class chart presented in Alexander and De Groot (1988) with low as Class 1, moderate as Class 2, etc. The units of measure are kilowatts per metre (kW/m); the english equivalent is Btu's per second per foot (Btu/(s.ft) [1 kW/m = .29 Btu/(s.ft)]. The intensity class levels for the chart were based primarily on fire suppression capabilities as determined by the expected fire behavior. The rate of fire spread levels used in figure 4 follow

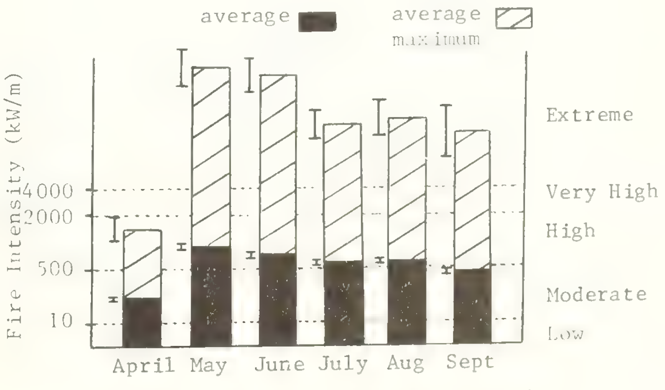

Figure 3--Historical frontal fire intensity potential in the Nisbet Provincial Forest based on level terrain, a mature jack pine fuel type, and fire weather data for 1953-80 (±1 standard error indicated by error bars on the left).

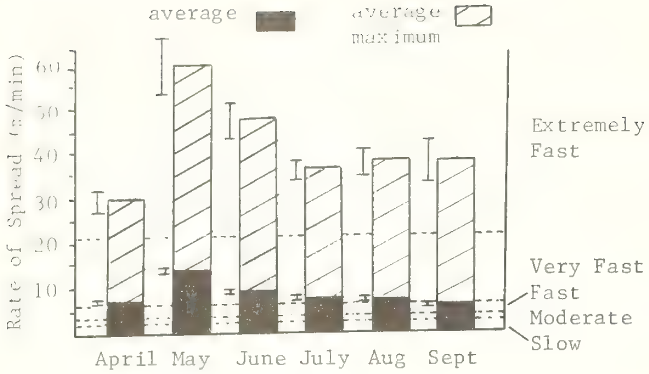

Figure 4--Historical rate of fire spread potential in the Nisbet Provincial Forest based on level terrain, an immature jack pine fuel type, and fire weather data for 1953-80 (±1 standard error indicated by error bars on the left).

those of the province of British Columbia (British Columbia Ministry of Forests 1983), with the exception of 22 m/min (72 ft/min) being used to separate Very Fast from Extremely Fast. For both figures 3 and 4, the average bar reflects a 28-year average of every day in that month; the average maximum bar reflects a 28-year average of only the single most severe burning day in that month.

THE NISBET WILDFIRE SCENARIO

In order to quantify potential area burned, several assumptions had to be made in the construction of the wildfire scenario.

Good ground access and fire detection capabilities in the Forest make it reasonable to assume that initial attack forces should be at the fire site no later than one hour after it starts. This state of readiness would certainly hold true on severe burning days, provided that a multiple-fire situation did not occur. For the purposes of the present exercise, each fire was allowed to burn freely for a one-hour period.

To get a reasonably accurate estimate of the probable area that would be burned over, a worst-case situation was created. Each one-hour fire growth projection was started during the peak burning period in mid-afternoon on the most severe fire weather day in each month of the normal fire season.

Two problems which needed to be addressed in the development of this scenario were in establishing the location and number of fire starts. Knowing fire locations would allow accurate selection of the fuel type and slope. As well, the area burned could be mapped overtop of values-at-risk using a simple elliptical fire growth pattern (Alexander 1985) as in the FBP System (Lawson and others 1985; De Groot and Alexander 1986). However, to simplify this scenario it was decided that selecting fire locations would not be done. Immature jack pine on level terrain was used for all fires since it is the most hazardous and predominant fuel type in this area.

Creating multiple-fire situations would also overcomplicate the scenario. It was decided that one fire per month occurring on the most severe fire weather day in each month would be sufficient to indicate the potential for area burned.

For the period 1978-82, noon weather observations from the Prince Albert weather station were used to calculate the FWI System component values (Van Wagner and Picket 1985). The simple elliptical fire growth model incorporated in the FBP System was then used to calculate area burned (McAlpine 1987). Table 1 summarizes the results of the one-hour free-burning fire growth simulations.

DISCUSSION

The historical fire potential of the Nisbet Forest indicates that it is an area of high fire danger. Historically, the average fireline intensity (from May to September, 1953-80) is classed as 'High' (fig. 3). Fires in this category are often surface fires of moderate vigor requiring heavy ground equipment and air support for control (Alexander and De Groot 1988). Also, at least one day of each month during the same period was classed as an 'Extreme' fire intensity day (fig. 3). Fires starting under such conditions become active crown fires and often exhibit 'blowup' or 'conflagration' type behavior which cannot be controlled. It should be noted that figure 3 was based on the mature jack pine fuel type because similar information is not yet available for immature jack pine. However, it is expected that immature pine would exhibit greater frontal fire intensities under similar conditions.

Figure 4 shows that the average forward rate of fire spread during the fire season (by month for April to September) is Very Fast (6-22 m/min; 20-72 ft/min). As well, at least one day of each month during the same period was classed as a day of Extremely Fast (>22 m/min.; >72 ft./min.) forward spread rates.

The results in table 1 show that there is potential for serious fires in the Nisbet Forest. Severe burning conditions are reflected in the components of the FWI System. Using the Initial Spread Index (ISI) to calculate probable area burned, it is apparent that most summer months have conditions which are conducive to a fire becoming 100-200 ha (250-500 ac) in size within an hour of ignition. Realistically, most of the simulated fires in table 1 would be uncontrollable if allowed to attain the one-hour size. The possibility of multiple fires should also be considered. Any fires that might still be burning during a period of critical weather could further complicate control problems. This could translate to over-extended suppression resources and a longer free-burning period for new fires. The point to realize is that this wildfire scenario is still a fairly conservative estimate of potential fire growth.

Table 1--Noon weather observations and potential area burned in the Nisbet Provincial Forest associated with the most severe fire weather day of each month during the 5-year period 1978-82. Fire size calculations are based on a single ignition burning uncontrolled for a one-hour period at midafternoon in an immature jack pine fuel type on level terrain

Date			Temperature		Relative	Wind Speed		Selected FWI System Components[1]			Area Burned	
M	D	Y	°C	(°F)	Humidity (%)	km/h	(mph)	FFMC	ISI	FWI	hectares	(acres)
5	14	78	20	68	26	26	16	91.5	19.6	25.9	141	348
6	3		24	75	36	28	17	90.2	18.2	31.2	105	260
7	25		25	77	34	33	20	90.8	25.3	47.8	162	400
8	7		22	72	41	46	29	89.3	39.3	49.5	198	489
5	27	79	26	79	31	30	19	91.8	25.1	31.0	186	460
6	18		23	73	35	30	19	90.5	20.8	25.5	128	316
7	20		31	88	40	19	12	90.8	12.5	18.4	75	185
8	1		25	77	38	33	20	90.1	22.8	37.8	133	329
5	20	80	24	75	22	37	23	93.4	45.1	88.4	356	880
6	12		20	68	42	35	22	90.4	26.5	50.4	160	395
7	27		23	73	21	19	12	92.5	15.9	32.9	136	336
8	22		17	63	45	37	23	87.7	19.8	34.2	82	203
5	15	81	5	41	41	41	26	89.0	29.5	47.6	147	363
6	26		27	81	32	33	20	91.8	29.1	56.4	212	524
7	9		22	72	32	28	17	88.3	13.8	30.1	55	136
8	28		28	82	37	26	16	91.0	18.3	38.1	121	299
5	25	82	26	79	29	35	22	92.2	34.3	43.2	253	625
6	30		21	70	37	31	19	91.4	25.0	50.1	174	430
7	1		23	73	60	31	19	88.1	15.6	37.7	63	156
8	7		19	66	55	41	26	85.7	18.3	20.3	57	141

[1] FFMC, Fine Fuel Moisture Code; a numerical rating of the moisture content of litter and other cured fine fuels. ISI, Initial Spread Index; a numerical rating of the expected rate of fire spread (combines FFMC and wind). FWI, Fire Weather Index; a numerical rating of fire intensity (combines ISI and a fuel availability index) that is used as a general index of fire danger.

CONCLUDING REMARKS

In the Nisbet wildland/urban interface area which has 1 500 permanent residents and a heavy recreational demand, a rapidly-spreading, high-intensity fire could be disastrous. An analysis of historical fire potential and the previous wildfire scenario demonstrated that these types of forest fires are distinctly possible.

Often a crisis is required for the general public to appreciate the seriousness of a situation. Perhaps the threat of catastrophic fire in the wildland/urban setting can be better communicated to landowners and recreationists by using fire danger rating to quantify potential fire damage and impacts.

REFERENCES

Alexander, M. E. 1982. Calculating and interpreting forest fire intensities. Canadian Journal of Botany. 60: 347-359.

Alexander, M. E. 1985. Estimating the length-to-breadth ration of elliptical forest fire patterns. In: Proceedings, Eighth Conference on Fire and Forest Meteorology; 1985 April 29-May 1; Detroit, MI. SAF Publ. 85-04. Bethesda, MD: Society of American Foresters: 287-304.

Alexander, M. E.; De Groot, W. J. [In press]. Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather Index (FWI) System. Edmonton, Alberta: Government Canada, Canadian Forestry Service, Northern Forestry Centre. Poster (with text).

Alexander, M. E.; Lawson, B. D.; Stocks, B. J.; Van Wagner, C. E. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim edition. Environment Canada, Canadian Forestry Service, Fire Danger Group. 73 p. + Supplements [First Printing July 1984; Revision and Second Printing September 1984].

British Columbia Ministry of Forests. 1983. Fire weather indices-decision aids for forest operations in British Columbia. Forest Protection Handbook No. 12. British Columbia Ministry of Forests, Protection Branch.

Brown, A. A.; Davis K. P. 1973. Forest fire: control and use. 2d ed. New York: McGraw-Hill. 686 p.

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index System . 4th ed. For. Tech. Rep. 25. Ottowa, Ont. Environment Canada, Canadian Forestry Service. 48 p.

Canadian Forestry Service. 1987. Canadian Forest Fire Danger Rating System--User's Guide. Three-ring binder (unnumbered publication). Canadian Forestry Service Fire Danger Group.

De Groot, W. J.; Alexander, M. E. 1986. Wildfire behavior on the Canadian Shield: a case study of the 1980 Chachukew fire, east-central Saskatchewan. In: Alexander, M. E., comp. and ed. Proceedings, Third Central Region Fire Weather Committee Scientific and Technical Seminar; 1986 April 3, Winnipeg, Man. Study No. NOR-5-05 (NOR-5-191) File Report No. 16. Edmonton, Alberta: Government Canada, Canadian Forestry Service, Northern Forest Research Centre.

Gale, Robert D.; Cortner, Hanna J. editors. 1987. People and fire at the wildland/urban interface--a sourcebook. In: Proceedings, wildland/urban fire interface workshop for social scientists; 1987 April 6-8; Asheville, NC. Washington, DC: U.S. Department of Agriculture, Forest Service. 71 p.

Harrington, J. B.; Flannigan, M. D. Van Wagner, C. E. 1983. A study of the relation of components of the Fire Weather Index to monthly provincial area burned by wildfire in Canada 1953-80. Inf. Rep. PI-X-25. Chalk River, Ont. Environment Canada, Canadian Forestry Service, Petawawa National Forestry Institute. 65 p.

Kabzems, A.; Kosowan, A. L. Harris, W. C. 1986. Mixedwood section in an ecological perspective, Saskatchewan. 2d ed. Tech. Bull, No. 8. Prince Albert, Saskatchewan: Saskatchewan Parks and Renewable Resources, Forestry Division, 122 p.

Laughlin, Jerry; Page, Cynthia, editors. 1987. Wildfire strikes home! Report of the national wildland/urban fire protection conference sponsored by U.S. Forest Service, National Fire Protection Association, and U.S. Fire Administration. Publ. NFPA No. SPP-86. Quincy, MA: National Fire Protection Association. 90 p.

Lawson, B. D.; Stocks, B. J.; Alexander, M. E.; Van Wagner, C. E. 1985. A system for predicting fire behavior in Canadian forests. In: Proceedings, Eighth Conference on Fire and Forest Meteorology; 1985 April 29-May 2; Detroit, MI. SAF Publication 85-04. Bethesda, MD: Society of American Foresters: 6-16.

McAlpine, R. S. 1987. Two BASIC programs for fire danger and fire behavior computations. For. Mgmt. Note 43. Edmonton, Alberta, Government Canada, Canadian Forestry Service, Northern Forestry Centre. 3 p.

Merrill, D. F.; Alexander, M. E., editors. 1987. Glossary of forest fire management terms. 4th ed. Publ. NRCC No. 26516. Ottowa, Ont. Natural Resources Council Canada, Canada Committee for Forest Fire Management.

Saskatchewan Parks and Renewable Resources. 1984. Wildfire action plan for the Nisbet Provincial Forest. Unpublished report on file at: Saskatchewan Parks, Recreation and Culture Prince Albert, Saskatchewan.

Van Wagner, C. E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. For. Tech. Rep. 35. Ottowa, Ont: Government Canada, Canadian Forestry Service. 37 p.

Van Wagner, C. E.; Pickett, T. L. 1985. Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. For. Tech. Rep. 33. Ottowa, Ont: Government Canada, Canadian Forestry Service. 18 p.

BE YOUR OWN BEST FIREMAN--DON'T DEPEND ON THE GOVERNMENT

Trooper Tom Lugtenaar

PROTECTING YOUR HOME

Do not depend exclusively on governments to protect your home. Understand that there are always breakdowns in communication and honest learning mistakes--unintentional, but constant. Knowledge is the most important factor in protecting people and homes from wildfire. A new book "Wildfire Across North America: From Dragon Slayers...What To Do About It And How To Save Yourself," is a comprehensive book for inexperienced homeowners, as well as for the professional firefighter.

In this book, a basic wildfire education begins with the use of baby dragons to illustrate and form a foundation. It gives a balanced look at the three fire ecosystems in North America. East, West, and Northern areas are explored in regard to conditions, seasons, traditional tools, and tactics.

Professional wildland firefighters will find concepts that differ from one region to another. This book lays the foundation for all firefighters to be more effective and safe everywhere. Emergency procedures in one area of North America may well differ from another area, so in this age of the Incident Command System (ICS), it is more important than ever to have a broad understanding of the diverse fire setting that is North America.

Fire Management Plans are explored, as is domesticating the wild dragon of the forest in order to use it to burn brush and even to do prescribed burns.

Following knowledge are the needs of the homeowner in terms of tools. Rural homeowners have a home situated in forested lands that they own and have direct control over. A "how-to" Fire Management Plan is a must. A simple step by step implementation of wise forestry practices such as thinning, pruning, fire trails, access roads, and establishment of shaded fuel breaks will ensure more productive forest lands, and secure them from wildfire. At least give a fighting chance to employing natural barriers to exploit the dragon's weaknesses and vulnerabilities, and ambush it long before it gets to your home.

Rural homeowners need:

1. Knowledge, such as from the book "Wildfire Across North America" and from contacts with State and Federal authorities;
2. A small pump such as the Shindaiwa GP-25, 300 feet of one inch fire hose, 10 feet of one inch suction hose, various fittings, and an aerating foam nozzle to make more efficient use of water;
3. Correct hand tools for your fire ecosystem including two fire rakes in the east or two pulaskis in the west or north, a five gallon backpack water pump set up to produce foam, and one drip torch;
4. Five gallons of foam concentrate; and
5. A 100 gallon water storage tank to store along with small pump and hand tools in a mini-fire truck.

Urban homeowners have a home in a subdivision where neighbors use lots of vegetation for privacy and beauty. Here homeowners do not own very much land, usually just a small lot. Hence, they have no direct control over adjacent lands. Mid- to southern California, or eastern pitch pine and jack pine, and even hardwood forests with wildfire histories are good examples, but even areas that don't commonly have wildfire histories can, during uncommon droughts, become danger areas for large fires capable to sweeping through subdivisions and neighborhoods.

Urban homeowners need:

1. Knowledge, such as from the book "Wildfire Across North America" and contacts with State and Federal fire authorities;
2. A larger, stronger pump and large storage of water to be able to completely encase the home in foam quickly. An Acme "Drop" Pump, 10 feet of two inch suction home, 50 feet of 1½ inch fire hose, 200 feet of one inch fire hose, various branch and reducer fittings, two foam nozzles, suction hoses and needle valves and fittings;
3. Large water storage tank such as a swimming pool, hot tub, or under ground water storage tank;
4. Five gallons of foam concentrate; and
5. One drip torch.

It is imperative to have an independent source of power and water, not city water, not an electric

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Trooper Tom Lugtenaar is Proprietor, Trooper Tom's Fire Protection Co., P.O. Box 44, Manzanita, OR 97130.

pump. Power and water often go out during fires in times of great need.

Additional information regarding the book and tools is available from the author.

COMPARING PUMPS AND MISSIONS

The Shindaiwa GP-25 pump has a 2 cycle engine, 1.8 horsepower, weighs 12.8 pounds. It pumps 36 gallons of water per minute and produces enough pressure to make good foam. This pump is so light, handy and durable that it is ideal for the rural homeowner.

This pump is also ideal for State and Federal fire control work. Normal pumps on fire trucks, and even the standard M-26 and Mark III pumps, are not mobile enough and pump too many gallons per minute to exploit small springs, brooks or potholes. Also, their costs are prohibitive for the average homeowner.

Many times water is near wildfires, but truck access is impossible due to steep terrain or vegetation blocking routes to the water source. With the GP-25, you can quickly take the pump with you on foot and exploit waters previously unreachable with a pumper on wheels.

Justification for Government purchases outside GSA for Forest Service use can be made on standard requisitions by stating the above reasons as to why this pump should be secured and carried as a back-up on standard fire trucks. It surely gives fire crews a completely new and needed capability.

The Shindaiwa GP-45 is a larger, two-stroke pump. It produces more volume in terms of gallons per minute, but does not seem to produce as much pressure as the smaller and cheaper GP-25. Also, it has 1½ inch suction and hose ports, all making it heavier, more gangly, and less handy. Through extensive testing, the GP-25 has proven superior in all respects over the GP-45. In Alaska, the GP-25 has been used to chase extensive large, hot tundra and taiga fires by simply exploiting the many potholes of water, knocking down several hundred feet of flame, picking up hose and pump, and running ahead to exploit another pothole and so on. The GP-25 is a tremendous boon to wildfire control.

The Acme "Drop" pump has a 2 cycle engine, 3 horsepower, and weighs 31 pounds. It pumps 100 gallons of water per minute, and produces enough pressure to make good foam. This pump is not as light and handy as the GP-25 Shindaiwa. The 2 inch suction and hose ports makes it more gangly to handle for running around with, but it does produce a lot more foam faster than the GP-25, which makes it much better suited for encasing a home and surrounding trees and shrubs in foam. Thus, it is the pump of choice for the urban homeowner, and still at a very low price.

THE CASE FOR FOAM

Foam, like water, cools the fire, but it also smothers it and keeps oxygen away. So, from the start it already has the one-two punch that water alone does not have.

The next great advantage is that it expands water and makes it go much, much further. It also has the timed release advantage over water. In other words, foam continues to release more penetrating and more efficient water as the bubbles in the foam continue to break down and release their hammering and continual effect on the heat smoldering under the foam blanket, for a long, long time. Water alone would have dispersed and vaporized, allowing uncooled embers to rekindle. The foam blanket itself causes vapor and humidity to be trapped and forced down into the smoldering mass, which in turn cools it more and more. Because of the soap in the water released from the foam, this water is wetter than regular water and breaks through surface tension and simply penetrates more efficiently than normal water.

It is biodegradable and environmentally safe. Basically, it is a super soap and homeowners are advised to wash their car with the pump and foam system to ensure adequate practice and confidence in employing the system for eventual use against a wildfire or structure fire. A good quality dishwashing soap like Joy or Dawn work almost as well as the new foam concentrates. The foam chemicals are better, as that is what they were developed for, but in a pinch, the dish soaps will produce a foam.

DEVELOPING CUSTOMIZED WILDLAND FIRE TRAINING TO PROTECT PEOPLE, HOMES AND OTHER RESOURCES AT THE URBAN/WILDLAND INTERFACE

James L. Murphy and Frank T. Cole

INTRODUCTION

Federal, state and local resource management agencies have special and unique responsibilities at the urban/rural/wildland interface. Prescribed fire and fire suppression training may be one of these responsibilities.

Agencies may use prescribed fire as a management tool and escape fires do occur. Sound training programs in fundamentally important subjects such as fire behavior are a must, both for agency personnel and cooperators, public and private. The job of developing and conducting fire for interface cooperators frequently falls to the wildland resource management agency and this is true of many National Wildlife Refuges in the U.S. Fish and Wildlife Service.

Escaped prescribed fires over the last 10 years in the National Refuge System have resulted in fatalities and the loss of millions of dollars of natural and man-made resources. One escaped prescribed fire on a North Carolina Refuge that burned onto private land resulted in a series of lawsuits costing the Government nearly $3.5 million. The Service recognized the critical need for the development and presentation of training programs designed to help fire practitioner personnel understand and apply the principles and processes of wildland fire behavior, fire suppression, and fire safety. Refuges and cooperators could not always afford both the expense and the time off the job necessary for refuge personnel to complete the extensive series of suppression courses (S-courses) and other multi-agency training available in some areas each year. Travel restrictions were increasing and training budgets were decreasing. The Service had very few people qualified to teach fire courses. Because of the unique nature of refuge locations, management objectives and problems, training had to be tailored to meet specific U.S. Fish and Wildlife Service needs. A customized basic wildland fire behavior, fire suppression, and prescribed burning training program was developed by the Service and applied in six Service Regions across the United States.

TRAINING PROGRAM DEVELOPMENT BY CONTRACT

In 1984, the Service contracted the development and conduct of the first series of courses to Fire Science Systems Corporation (FSS) of California and Boise, Idaho. The FSS team responsible for the training development consisted of wildland fire specialists, a wildlife biologist and training specialists.

JOB AND TASK INVENTORY AND ANALYSIS

FSS Corporation specialists conducted an in-depth analysis of jobs and component tasks of those jobs, which made up or should have made up, the Fire Management Function of the U.S. Fish and Wildlife Service.

The inventory and analysis of jobs covered those performed by personnel permanently or only occasionally assigned to fire management jobs on Refuges within the National Refuge System.

The Job and Task Inventory and Analysis defined 19 discrete job requirements making up the Fire Management Function.

Each job was then broken down by:

1. Tasks making up that job.
2. Steps necessary to carry out and complete the tasks.
3. Standards for completing the task.
4. Conditions under which the jobs and task were to be performed.

The primary purpose of the job and task analysis was:

1. To identify the skills/knowledge requirements necessary to safely and effectively carry out jobs and tasks.
2. To define the training requirements of Refuge System personnel to perform effectively and safely their job assignments.

The Job and Task Inventory and Analysis served other purposes also: for example, aids to

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James L. Murphy is President, Fire Science Systems Corporation, Boise, ID.

Frank T. Cole is Fire Management Coordinator, U.S. Fish and Wildlife Service, Boise Interagency Fire Center, Boise, ID.

developing a Refuge fire management organization, job descriptions, performance evaluations, and special training and job requirements necessary to deal safely and effectively with the unique cooperative and fire problem at the urban/rural/wildland interface.

The Job and Task Inventory and Analysis indicated the priority needs for training existed at three levels:

Level I	Basic Prescribed Fire, Firefighting, and Fire Safety Training.
Level II	Fire Supervisory ("Overhead") training.
Level III	Fire Management Specialist training.

The development of "Level I Training," a course titled "Basic Fire Management" was the principle goal of the contract and project.

SERVICE STEERING COMMITTEE

A Steering Committee representing the Service at the Washington Office, Regional Office, and Refuge level, and the Service Fire Management Staff at the Boise Interagency Fire Center was chartered. The Committee guided the development of the Job and Task Analysis and the Basic Fire Management Training Program.

THE DESIGN OF BASIC FIRE MANAGEMENT TRAINING

Basic Fire Management was developed to meet a need for basic instruction in:

- Wildland Fire Behavior
- Planning and application of prescribed fire
- Basic initial attack fire suppression principles, strategies and tactics
- Fire safety
- Team participation and operation
- Smoke management principles and techniques

Basic Fire Management was aimed at personnel with little previous training who had some responsibilities for prescribed burning and for initial attack fire suppression.

The basic rationale underlying training requirements as defined by the Job and Task Inventory and Analysis and Refuge personnel is shown sequentially in Figure 1.

The structure of Basic Fire Management training is show in Figure 2.

A series of subjects were identified which were basic and prerequisite to prescribed burning and fire suppression, for example, fire behavior, and lesson plans for these subjects related to both specialty areas.

Another series of subjects were identified which had post-burn application to both specialty areas, for example, mop-up and patrol, and lesson plans relating to both areas were developed.

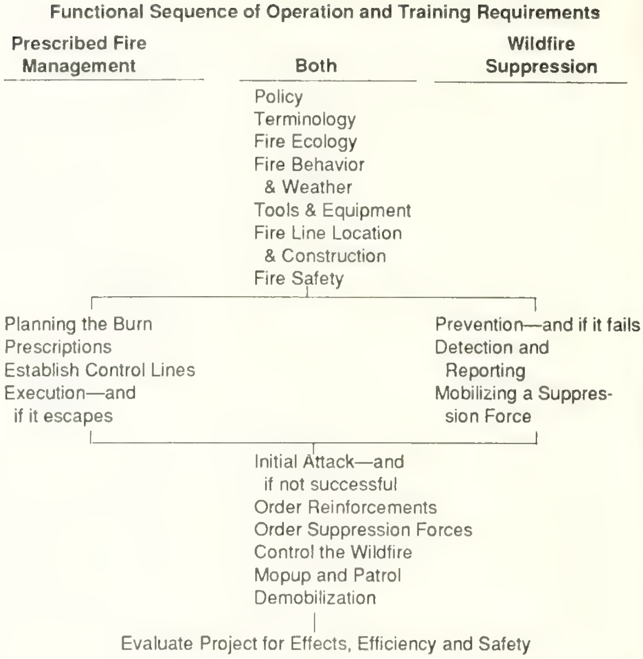
Functional Sequence of Operation and Training Requirements
Prescribed Fire Management
Both
Wildfire Suppression
Policy
Terminology
Fire Ecology
Fire Behavior & Weather
Tools & Equipment
Fire Line Location & Construction
Fire Safety
Planning the Burn
Prescriptions
Establish Control Lines
Execution—and if it escapes
Prevention—and if it fails
Detection and Reporting
Mobilizing a Suppression Force
Initial Attack—and if not successful
Order Reinforcements
Order Suppression Forces
Control the Wildfire
Mopup and Patrol
Demobilization
Evaluate Project for Effects, Efficiency and Safety

Figure 1--Relationship of prescribed fire and wildfire.

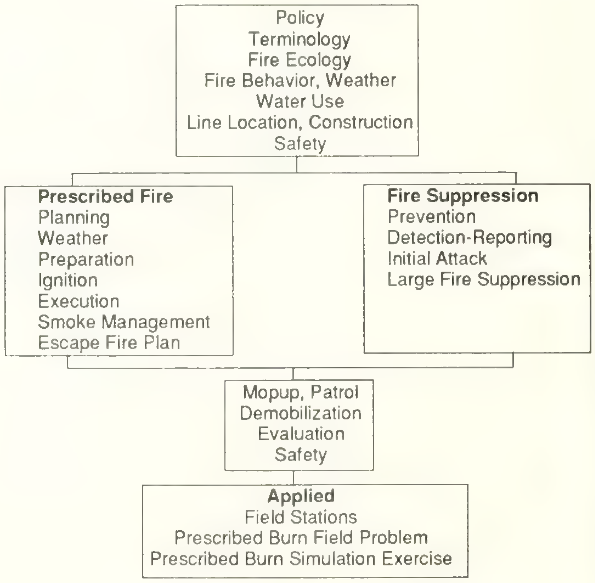

Figure 2--The Structure of Basic Fire Management Training.

The sequential flow of training emphasis is shown in Figure 3. In order to minimize time away from the job as well as travel and other costs, some 25-30 hours of prerequisite subjects were completed (with testing) at the student's home location. Prework assignments also served to bring students to a common level of technical knowledge and understanding.

An important segment of the 36 hour classroom session was the field follow-through. Students organized by teams were given hands-on instruction

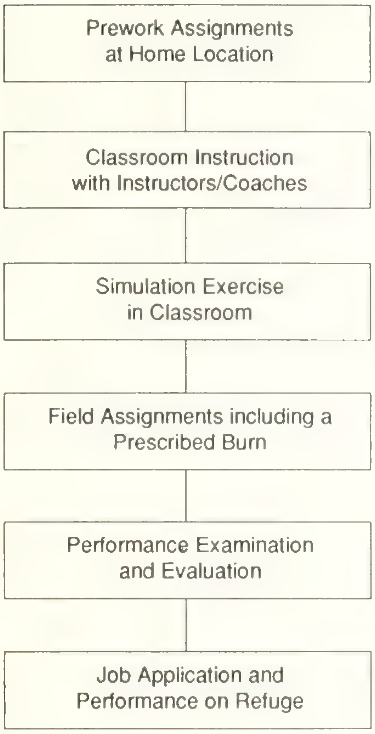
Prework Assignments at Home Location
Classroom Instruction with Instructors/Coaches
Simulation Exercise in Classroom
Field Assignments including a Prescribed Burn
Performance Examination and Evaluation
Job Application and Performance on Refuge

Figure 3--Sequential flow of training and applications.

and practice in tool and equipment use and safety, weather and fire behavior measurements, fire safety including use of the fire shelter, helicopter safety, pumps and water delivery systems. Each student team also planned, prepared for, and carried out an actual prescribed burn and their performance was evaluated by the course instructors acting as coach/evaluator.

Training materials prepared for Basic Fire Management training included:

- Reference texts for all subjects
- Lesson plans for all subjects
- Prework unit
- Visual aids including .35 mm slides
- Student notebooks
- Instructor notebooks
- "How-to-do-it" handouts

SYNERGETIC EDUCATION

To make possible the equivalent of 160 hours of training in just 36 hours in the classroom, Fire Science Systems Corporation has developed and copyrighted Synergetic Education, a system of principles, methods and techniques tailored to specific training courses to enhance the learning process and to make learning more fun and satisfying for the student. Some of the Synergetic Education processes applied to Basic Fire Management were:

1. Specially tailored prework assignments and examinations done at student's home refuge.
2. "Hands-on" class and field exercises including a simulated and live prescribed burn.
3. Student teams with team leaders.
4. The Organization of course cadre as team coaches.
5. Dynamic team-cadre feedback processes applied several times a day for course quality and learning experience corrections.
6. Tutoring and evening sessions.
7. FWS instructor training and development.

UNIQUE FEATURES OF THE SERVICE TRAINING PROGRAM

1. For the first time, the Service has developed an educational program combining prescribed fire with initial attack fire suppression, based on fire behavior principles all integrated with policy, safety, and management/supervisory principles and practices.
2. This adult education program was:
    a. Non-traditional. The Service developed the program to meet its unique management and safety requirements. "Canned" traditional training courses were not used.
    b. On-the-job performance oriented: focused on safer and better jobs.
    c. Success oriented, building in fail-safe operational and safety principles and techniques related to Refuge conditions.
3. Students completed the equivalent of 160 hours of training in just 36 hours of formal classroom work off the job through:
    a. At-home study assignments.
    b. Use of teams, team leaders and coaches.
    c. Classroom work directly combined with field application.
    d. Live training burns in the field as part of the training.
    e. An interactive prescribed burning and initial attack simulation problem.
    f. Special evening team assignments.
4. The Fire Education Program was especially appealing to Interface Cooperators because it was basic, required minimal time in formal classroom work, and emphasized cooperative principles and action.
5. Educated nearly 250 Refuge employees in six Regions and cooperators in fire behavior, suppression, prescribed burning and fire safety in less that 1½ years.

The Service's Basic Fire Management program exceeds the requirements of the required courses for a National Interagency Firefighter:

a. S-110, S-130 Basic Firefighter.
b. S-190, Fire Behavior.

Under traditional training programs each student would be required to attend all or major portions of 16 different Interagency "S" Courses to receive the equivalent training and, by necessity, the training would be spread over 3-5 years.

6. Each student was asked to evaluate the program. Ninety-seven percent of all students completing the training said:

   a. "Objectives were met," "quite to extremely well."
   b. They would recommend the course to others.
   c. The course "Fits their needs; practical, usable on the job."

7. Thirteen Fire Management Specialists were trained as Instructors and Coaches and became the "Cadre" to carry on the program and to further refine and adapt it.

8. Team operation and supervisory/managerial skills were taught to students. Refuge personnel learned the importance of team decision-making in fire operations, and that a qualified maintenance worker on a Refuge could be an Incident Commander, supervising a Refuge Manager.

9. Safety awareness and how to apply safety principles on the job has resulted in few minor injuries and no serious injuries or fatalities during burn or fire suppression assignments since the program began in 1985.

CONFLAGRATION PREVENTION SYSTEMS AT THE URBAN WILDLAND INTERFACE:

HIGH RISK FORECASTING AND TOTAL MOBILITY

James L. Murphy and Troy Kurth

ASTRACT: This paper described a first-time Forest Service Regional conflagration fire prevention plan put into action in southern California. Ninety-eight prevention specialists from the Forest Service North Zone and the Pacific Northwest Region along with Bureau of Land Management personnel were organized into twelve task force teams and moved to southern California. A fire occurrence forecasting center was set up at the Riverside Fire Laboratory. Special computer programs produced occurrence forecasts, by cause, for each Ranger District on each of the four National Forests.

The conflagration potential is 200 percent above average!

This was the situation on the four southern California National Forests in September 1979 when the first ever conflagration prevention plan was implemented. Saturation prevention action was taken as the fire danger worsened to prevent conflagration potential wildfires from starting.

Conflagrations or large disaster fires are a primary concern of wildland firefighting organizations everywhere.

Suppression costs on wildland fires in California, for example, are frequently in excess of $150,000 for a 300-acre fire and can exceed $2.5 million for a 10,000-acre fire. Conflagration fires occur all too frequently in high value watershed and areas of urban development where losses of $3,500 per acre are not uncommon.

Conflagration fires in southern California most often occur during conditions that are predictable such as low fuel moisture and high velocity dry winds. These conditions are associated with well understood weather and other physical phenomena. This same predictability is true for the Intermountain West.

Experienced fire managers know that the surest way to control conflagration fires is to prevent them in the first place. Yet, wildland fire prevention is given only token emphasis in terms of allocation of resources and financing, in most wildland management agencies in the United States.

Historically when conflagration conditions occur, some fires start and the prevention organization is quickly assigned to fire suppression duty. Prevention of the next fire is then nearly impossible.

One reason for this lack of emphasis on fire prevention is that historically, predicting the chance of a wildfire starting has not been possible with any reliability, and efficient operational systems for fire prevention have not been developed and applied.

This paper describes a first-time test on a conflagration forecasting system and the application of total mobility, or move up systems to the prevention of conflagration fires.

CONFLAGRATION FIRE PREVENTION COORDINATION PLAN

In August 1978, the USDA Forest Service's California Regional Forester approved the Conflagration Fire Prevention Coordination Plan.

The plan focused on the four southern California National Forests:

1. Angeles National Forest
2. San Bernardino National Forest
3. Cleveland National Forest
4. Los Padres National Forest

The plan outlined the criteria for implementation of, and the action to be taken by intensified fire prevention systems during periods of extreme fire danger. The overall objective of the plan, and action, was to reduce the likelihood of the occurrence of large disaster wildfires--the conflagrations.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

James L. Murphy is President, Fire Science Systems Corporation, Benicia, California. Troy Kurth is Forester, Aviation and Fire Management, USDA Forest Service, Missoula, Montana.

CONFLAGRATION EARLY WARNING SYSTEM

Each of the four southern California National Forests was separated into areas of low, moderate, high hazard and exempt areas.

Exempt areas were those relatively "fire safe," such as large expanses of rock and/or barren ground.

Hazard areas were classified on the basis of:

1. Predicted rate of spread.
2. Spotfire potential.
3. Presence of fine ground fuels, easily ignited.
4. Continuity of fuels which would permit spread over large areas.
5. Presence, or absence, of manmade barriers.
6. Resistance to suppression factors, such as machine operability, access.
7. First run damage potential of a fire that starts.

CRITERIA FOR PLAN ACTIVATION

Criteria for activation was based on the hazard areas, previously discussed, the two principle southern California fuel models, rate of spread potential and the computer-based analysis of fire report data.

The potential rate of spread was set at 80 chains per hour. This spread rate could be expected to result in a 300-acre fire in 1 hour when average slope percent and spotfire potential was included.

The two computer assisted programs were:

1. "Crosstabs" which allows for cross tabulated analysis of Forest Service fire report data where a constant (number of smoker fires) is analyzed against several variables (such as time of day, fuel types, or locations). The analysis is helpful for longer range planning purposes.

2. "Prevent Query" which allows for continuous monitoring of day-to-day fire occurrence within each of 300 fire prevention units in the National Forests in California. "Prevent Query" makes possible the comparison of current fire occurrence trends to the historic trends obtained from "Crosstabs" analysis of individual fire reports.

IMPLEMENTATION OF THE PREVENTION ACTION PLAN

On September 15, 1979, worsening fire danger conditions in southern California resulted in high hazard National Forest areas meeting the criteria for the implementation of the conflagration prevention plan. Ninety-eight prevention specialists from the Forest Service North Zone (northern California) and the Pacific Northwest Forest Service Region (Oregon and Washington) and from the Bureau of Land Management were dispatched to southern California for saturation wildfire prevention activities.

PREVENTION COORDINATION CENTER

A Prevention Coordination Center was set up by the South Zone Coordinator at Riverside, California, Zone Headquarters. National Forest fire prevention officers requested prevention task force units through the coordinator.

PREVENTION TASK FORCES

The 98 prevention specialists were organized into task forces and units. A task force consisted of five radio-equipped fire prevention units. A fire prevention unit was two prevention specialists in a pickup/pumper unit.

RISK FORECASTING CENTER

The Risk Forecasting Center was set up at the U.S. Forest Service Riverside Fire Research Laboratory. The forecasting operation consisted of a team of analysts (statistical and computer specialists) and a team of strategists/tacticians (fire behavior officer/weather forecaster).

Fire occurrence forecasts were made by the team of analysts by National Forest, by Ranger District, and by cause.

A problem summary was prepared by the team of strategists and prevention action was recommended. Appendix 1 is an example of a fire occurrence forecast and problem summary.

FIRE PREVENTION TASK FORCE ACTION

The task force teams were assigned to prevention activities on the basis of the occurrence forecasts. The task forces augmented the regular Forest prevention crews for:

1. Saturation patrols.
2. Public contacts in high risk areas.
3. Road closures.
4. Contacts with local newspapers and television.

THE PAYOFF FROM THIS FIRST-TIME CONFLAGRATION PREVENTION PROGRAM.

1. Arson fires which were of high frequency on at least two of the forests were eliminated during the high fire danger period.

2. The units had "implied enforcement" effect on all four of the Forests, as reported by the Forest prevention officer.

3. On one National Forest the prevention units discovered three incipient wildfires and carried out successful initial attack.

4. On one Forest, fire prevention units made successful initial attack on 10 wildfires. Each prevention unit, with its pickup/pumper, radio communication, and tools could act as a fire suppression unit also.

The cost of this first-time experimental conflagration prevention project was $235,000. The estimated suppression costs saved by the intensified prevention action totaled $2.3 million.

The task force teams were assigned on the basis of the forecasts and carried out saturation prevention measures.

Prevention units (five to a task force) consisting of two prevention specialists with a radio-equipped pickup/pumper also detected fires and made initial attack on 10 wildfires.

The cost of this first-time experimental conflagration prevention project was $235,000. The estimated suppression costs saved totalled $2.3 million.

Appendix 1

Date: September 27, 1979

Fire Occurrence Forecast for the Week of September 29 to October 6, 1979
by
Fire Prevention Research Unit of PSW

San Bernardino National Forest

Summary:

The chance of one or more fires this week is: 0.947

The most likely causes are:

a. Equipment
b. Smoking
c. Campfires
d. Incendiary
e. Children

The chance of one or more fires during Saturday or Sunday is: 0.812

The chance of one or more fires on any weekday is: 0.732

The most likely occurrence for the week is 1 to 5 fires.

Summary by Ranger Districts

The chance of one or more fires this week is:

Cause	Arrowhead RD	Big Bear RD	Cajon RD	San Gorgonio RD	San Jacinto RD
Equipment	.10		.30		
Smoking	.59	.32	.10		
Campfires		.35	.13	.12	
Debris					
Railroad			.14		
Incendiary	.46		.42	.43	.10
Children	.56	.55			
Miscellaneous	.20				
Total	.86	.76	.70	.45	.22

FIRE PREVENTION PROBLEM ANALYSIS SUMMARY
for
San Bernardino National Forest

September 29-October 6, 1979

Problem Summary

The chance of one or more fires starting on the forest during the following week is almost certain. There is a high probability of incendiary fires based upon trends of the last week. Equipment use fires and smoker fires show moderately high chances of occurrence. Incendiary fires will most likely occur on the San Jacinto and Arrowhead Ranger Districts and the Santa Ana River drainage of the San Gorgonio District. The chance of equipment use fires is highest on the Cajon District. Campfires and smoker fires may occur on the Arrowhead, Big Bear, San Gorgonio, and San Jacinto Districts.

Analysis of historical data indicates:

1. The chance for an incendiary fire over 300 acres is greatest on the San Jacinto District.

2. Transients cause 58 percent of all incendiary fires, but local permanents may cause 17 percent. Visitors cause 17 percent also.

3. The odds are that most incendiary fires will start between 1100 and 1700. The chances are 3/10 that an incendiary fire may start between 0300 and 0600, however.

4. Though 84 percent of all incendiary fires had little or no "degree of preventability," 16 percent of them might have been prevented. Personal contact was the recommended activity.

Prevention Action

Equipment use, smoker fires, and fire caused by campfires can be prevented.

1. Check stations on the San Gorgonio and San Jacinto Districts.

2. Campground patrol.

3. Personal contact on all industrial operations.

Some incendiary fires can be prevented.

1. Intensify patrols between the hours of 1100 and 1700 and 0300 and 0600.

2. Contact local permanents, especially on the San Jacinto and San Gorgonio Districts.

3. Establish check stations with the help of the local sheriff's office.

Analysis by: Jim Murphy

FIRE HAZARD REDUCTION PROGRAM IN THE HILL AREA OF THE UNIVERSITY OF CALIFORNIA AT BERKELEY

Carol Rice and Elaine Bild

ABSTRACT: The University of California at Berkeley has instituted a five year program to reduce the fire hazard in the 1500 acre Berkeley Hill Area. Treatments to reduce fire hazard are linked to the current vegetation types. Vegetation types include Monterey pine, grass, north coastal scrub, oak/bay woodlands, and thirteen year old sprouts of eucalyptus. Treatments consist of hand labor, prescribed burning, goat grazing, as well as cutting and chemically treating eucalyptus sprouts. Cooperation and involvement of local agencies and the community are an integral part of the program.

BACKGROUND

The University of California has a serious fire hazard above the Berkeley campus (i.e. the Hill Area). The vegetation in the Hill Area is often flammable. Not only is the volume of fuel large, but also much of it is dead. Valuable and reknown research facilities are almost universally located above slopes of natural fuels. The high recreational usage of the Hill Area increases the chance of ignition. In 1986 alone, for example, three arson fires burned in the Hill Area. Severe fire weather and steep slopes only compound the threat.

Fire protection capabilities have improved since a 1923 fire, in which 584 structures were destroyed. However, there have been other devastating fires since then. A fire in 1970 burned 39 homes just one ridge south of the UC Hill Area. Damage was estimated at $3.5 million. A fire in 1980 burned five homes northeast of the campus. It occurred December 14th, after fire season had closed. The first engine arrived in just six minutes, but four homes were already engulfed in flames. Damage was estimated at over one million dollars.

PLANNING PROCESS

A fire prevention committee was formed to aid in program planning and implementation. This committee has a diverse representation, including homeowners, local fire departments, as well as University adminstrative and academic departments. Goals for the preferred amount and arrangement of fuels as well as the distribution and successional stage for each vegetation type were agreed upon before site specific action plans were developed. Generally, the combined goals are to encourage native plants of low fire hazard.

THE PROGRAM

Prevention of a potential catastrophe is critical. This realization prompted the University Office of Environmental Health and Safety to initiate a five year program which prescribes and schedules activities to reduce the fire hazard. These activities include: biological and chemical treatments, hand labor, prescribed burning, and compatible land uses. In many situations, a combination of these treatments is applied.

Costs of methods vary widely, so proposed methods balance environmental impact, effectiveness of fire hazard reduction, and costs. Hand labor costs range from $200/acre to $1015/acre. Goat grazing ranges from $300/acre to $1000/acre. Prescribed burning ranges from $30/acre to $300/acre. Cutting and treating eucalyptus is estimated at $435/acre. This estimate incorporates expenses of $1415/acre to cut and chemically treat eucalyptus stumps, plus income of $850/acre from the sale of the boles of the trees as firewood.

The highest priority areas to treat are those on the University borders and those adjacent to high value facilities. These areas are scheduled to be treated first. The activities as well as their scheduling and placement incorporate concerns for fire safety, environmental protection, and cost efficiency.

Management activities to reduce fire hazard either change the vegetation type or reduce the fuel volume within a vegetation type by: (1) reducing total amount present to burn; (2) spacing the vegetation (both horizontally and vertically) so flames have to reach farther to continue their spread; and (3) reducing flammability of the fuels. A mixture of these methods is often used.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Carol L. Rice is Proprietor, Wildland Resource Management, Walnut Creek, CA; Elaine Bild is Director, Office of Environmental Health and Safety, University of California, Berkeley, CA.

The UC Hill Area encompassed two dairy farms in the 1800's. Fuel treatments such as eliminating eucalyptus sprouts and reduction of brush cover reconstruct a more natural ecosystem. This aspect of the program is doubly important in a large portion of the Hill Area designated as an Ecological Study Area.

Input from several experts was invited to clarify environmental concerns. Some interested parties believe there is no fire problem in the Hill Area which warrants any action. Consideration of all concerns resulted in the establishment of a wildlife refuge, preservation of an area of each vegetation type in an untreated condition, and treatments to further protect local fauna.

PLANS

Management treatments are linked to vegetation types because fire burns through each type differently.

In Monterey pine (Pinus radiata) stands, hand labor will be used to clear out undergrowth, then prescribed fire will be used to reduce dead and down material. Thus the mature stand will be left intact.

Most oak/bay woodlands will receive no treatment because they are not a major fire hazard. We will separate the canopy from ground fuels by six feet or more in woodlands adjacent to homes.

We will conduct prescribed burns in grasslands below structures before July 4th every year. Other grsasslands will be burned at five year intervals in a manner that will promote conversion of exotic annual to native perennial grasses.

In areas with permanent fences, where hand labor is not economical, or in areas of poison hemlock (Conium maculatum) and poison oak (Toxicodendron diversalobum), a herd of goats will be grazed. Approximately 600 goats are concentrated in a fenced area for a short period of time in order to reduce the plant volume and fire hazard. While non-traditional in most fire hazard reduction programs, this treatment has proven to be quite successful in an urban/wildland setting.

In 1972 a freeze killed the branches of eucalyptus and 100 acres were cut with the belief they were totally dead. As result, the sprouts now constitute the worst fire hazard in the Hill Area. We will convert the areas of eucalyptus (Eucalyptus globulus) sprouts to grass on south slopes and oak/bay woodlands on northern aspects. This entails cutting the boles and selling the boles as firewood or chips. Leaves and branches will be left to dry and will be burned in the spring. This treatment has an aspect of urgency because a eucalyptus beetle (Phoracantha semipunctata) is moving north from Southern California. The beetle girdles the tree, changes the growth form of the trees to brush and renders the wood unsalable. Prescribed fire will be used in areas of mature eucalyptus to maintain an open canopy and low amount of fine fuels.

We will rejuvenate decadent stands of north coastal scrub, or promote the natural advancement to oak/bay woodlands. Shrub cover will be reduced to 20% intermixed in rocky outcrops and in grass.

Approximately 65 acres are scheduled to be treated in the first year, 200 acres in the second, gradually decreasing to 71 acres the fifth year. The cost of implementation rises from $26,000 the first year to $54,500 the second, then tapers to $11,000 the fifth year. An estimated 40 percent of the fire management costs can be attributed to precautions taken to minimize environmental impact.

RESULTS

Fire intensity (as measured by flame length) is predicted to decrease approximately 50% as a result of the management activities. This further indicates an increase in the ability of suppression forces to control the fire. The most dramatic improvement in fire safety is expected to occur from the eradication of eucalyptus sprouts.

Meetings with homeowner groups and the involvement of the diverse fire prevention committee have been an essential part of the program's success. Other public affairs activities are also being performed, including coordination with the news media.

The first year of the program is proceeding well. Approximately 50,000 hours of hand labor were spent on this program by the California Conservation Corps. These young adults have pruned and thinned stands of pine and eucalyptus as well as built fire lines, all in anticipation of prescribed burns. We have conducted two prescribed burns, both bordering homes. The first was a prescribed burn in a Monterey pine stand. The second was in a combination of grass, eucalyptus and brush. We also grazed 600 goats, concentrated in areas where other manipulation was not feasibile. Public response has been enthusiastically supportive; goat grazing has been the most popular method and concerns over smoke and blackened hills is minor. Although opposition to other eucalyptus eradication programs exists elsewhere, so far, local homeowners have met this restoration project with favorable response. A site-specific eucalyptus removal plan is being developed. Poison oak presents the most major obstacle at this time, for it limits hand work in areas where it is prevalent. A third prescribed burn across the street from the football stadium is to occur as soon as weather permits.

Cooperation is integral to the plan. The program benefits many sectors of the community. A UC professor conducts prescribed burns as an educational tool. The California Conservation Corp is heavily involved. Local fire departments (especially that of the Lawrence Berkeley Laboratory) assist in prescribed burns, providing firefighters and equipment. Faculty and students will realize increased opportunity for research and educational activities in the Hill Area. Much of the area made inaccessible by brush will be more open to recreationists. Homeowners have given this plan solid support. Nature enthusiasts appreciate the restorative aspect of the program.

PROTECTING PEOPLE AND PROPERTY FROM FIRES IN WILDERNESS

James M. Saveland

ABSTRACT: Wilderness is "recognized as an area where the earth and its community of life are untrammeled by man." Thus, one of the objectives of wilderness fire mangement plans is to permit lightning caused fires to play their natural ecological role within wilderness. However, one of the most important elements in a wilderness fire prescription is safeguarding people and property.

There is considerable uncertainty surrounding a decision to permit a lightning fire to burn under prescription, not knowing what the weather will be like for the remainder of the fire season. There is a certain amount of risk inherent in each decision. Risk management includes identifying the risks, assessing the probabilities and consequences of various events, and evaluating risk mitigation measures. Decision theory provides an excellent framework to identify and quantify the risk management process.

Protection concerns in wilderness include visitor safety and permitted operations, such as outfitte camps and private in-holdings. Government property, such as ranger stations, trail bridges, and lookouts, need protection too. Risk mitigation measures include educating the public about wilderness fire programs, taking suppressio action against fires that pose a threat, and informing the public of the current fire situatio as it develops via signing, personal contact, and the media. Trail closures are often necessary in the vicinity of a fire, and airfields have been temporarily closed in the past because smoke has restricted visibility. Planned ignition prescrib fires may be necessary in some wilderness areas to further reduce risk.

The problem of protecting people and homes from wildfire is not limited to wildland residential areas. Many of the same problems exist in more remote settings. There are many lessons to be learned from how established wilderness fire programs have already dealt with this problem.

Poster paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

James M. Saveland is Fire Management Officer, Moose Creek R.D., Nez Perce N.F., Forest Service, U.S. Department of Agriculture, Grangeville, ID.

RELATIONSHIPS OF WATER, WET WATER, AND FOAM TO WILDLAND-URBAN INTERFACE FIRE SUPPRESSION

Paul Schlobohm and Ron Rochna

ABSTRACT: Consequences of recent fires demand more effective means of fighting wildland-urban interface fires. Fire suppression properties of water, wet water, and foam are examined as they influence application guidelines. Modern water attack requires high flow rates. Wildland foams combine the best attributes of water, wet water, and other foams. Indirect water attack on structures may have practical applications for wildland foam in the interface. Water should not be used to fight fire without a surfactant.

INTRODUCTION

The wildfires in California and Oregon during the late summer of 1987 were devastating reminders of the conflicts created by homes in the wildland.

Nine lives, over 60 structures, and at least 850,000 acres of timber were lost in California alone (Rios, 1987). The large number and size of the fires quickly depleted resources. Suppression strategies necessarily shifted to human and structure protection at the expense of timberlands. The increased need for property protection and efficient resource use attracted much attention to wildland fire foams.

To understand the merits of wildland foams as a tool for fire suppression in the wildland-urban interface, an examination of the development and use of foam for firefighting is appropriate. The relationships of plain water and its foam additives are shown in table 1.

Current wildland and structure fire suppression efforts in the United States rely almost entirely on plain water. The most common water additives include aerial retardants for wildland fires, and vapor suppressant foams for industrial and crash fires. Wet water is used sparingly for mop-up by wildland and urban fire forces. Foam for wildland fires has a small and growing following.

WATER

Water has been recognized as a means of suppressing fire since rain was first observed extinguishing the warming fires of early man. Water is transportable. It is neither corrosive, toxic, nor reactive. Water has one of the highest cooling capacities; requiring the absorption of 9330 btu per gallon as it boils and then becomes steam. Layman (1955) found the conversion of water to steam to be 90 percent efficient with high pressure and low water flow. Layman's rapid, low water flow tactics which did not include structure entry, may have applications for the wildland-urban firefighter. The water droplets he projected into superheated spaces expanded 1600 times to steam forcing heat and oxygen out of the building.

With the advent of breathing apparatus in the 1960's, Grady (1987) notes that structure fires have been attacked from inside and out. Moving personnel inside necessarily changed water flow tactics to prevent injury from superheated steam. Water streams were applied directly to the fire, requiring more applications, and more water than before. The Iowa formula is the current water flow guide for interior structure attack:

$$\text{gallons per minute} = \frac{\text{cubic feet of largest room}}{100}.$$

The molecular structure of water influences its vaporization and effectiveness as a fire suppressant. Each molecule has two hydrogen atoms bonded asymetrically to one oxygen atom. The resulting polarity gives the molecules a strong mutual attraction manifested in a high surface tension of 73 dynes/cm at 20°C. Strong surface tension forms water into beads or drops rather than films. Because of water's surface tension, utilization of water droplets to make steam and cool fire is rarely complete. Haessler (1974) notes that a solid stream of water is 5-10 percent efficient at actual extinguishment. The Iowa Formula has a built-in effectiveness factor of 40 percent (Grady, 1987).

Another gauge of water effectiveness is the water flow rate required by the Insurance Services Office (1980). For a 1-2 family dwelling not exceeding two stories in height and at least 100 feet from other dwellings, the Office states that 500 gallons per minute must be available to protect this house.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Paul Schlobohm and Ron Rochna are Fire Management Specialists, Boise Interagency Fire Center, Bureau of Land Management, U.S. Department of the Interior, Salem, OR

Table 1--Relationships of water, wet water, and detergent-based foams

	WATER						
Add	Nothing	Surface Active Agent					
Agitation?		No Agitation	Agitation				
Result	WATER	WET WATER	MECHANICAL FOAM				
			Common Features				
Type of Foam			Wet Water Foam	Detergent Foam	Wildland Foam	High and Medium Exp. Foam	Aqueous Film-forming Foam
Date Introduced		1950's	1950's	1930's	1980's	1950's	1960-70's
Surface Tension (dynes/cm)	73	25-33					16-19
Mix Ratio (%)		0.05-0.1	1,3,6	1,6	0.2-0.7	1,3	3,6
Major Use: Fuel Class and Applications	A: -Extinguishment -Mop-up	A: -Mop-up: wet charred fuels and textiles	A & B: -Bulk Fuel fires -Rapid knockdown	A & B: -Combination use for departments with variety of fuels	A & B: -Wet charred, uncharred, dead, living fuels -Exposure insulation -Rapid knockdown -Mop-up	A & B: -Confined space fires -Exposure insulation	A &/or B: -Aircraft crash control -Rapid knockdown -Diked fuel spills -Polar solvents

The specific gravity and heat transparency of water also affect its use. Because most hydrocarbons have a lower specific gravity, they float on water. Therefore, water has no resistance to reignition and flashback. Since water is a poor reflective barrier to radiant heat, continuous, high volume water flows are necessary for exposure protection.

SURFACTANTS

To improve the wetting, penetrating, and durability characteristics of water, man has been adding surface active agents for over fifty years (Ratzer, 1956). The surface active agent, or surfactant, reduces the surface tension of water to 17-30 dynes/cm, allowing elasticity of water surfaces and greater mobility of water molecules. Surfactants have been developed for specific functions on certain fuels. A surfactant made to adhere as foam to plastics, for example, will differ from one made to create a film seal over petroleum products.

Surfactants for firefighting can be roughly grouped as either wetting agents or foaming agents. Wetting agents increase the spreading ability of water and usually are not designed for use as foam. Surfactant foaming agents have wetting agent properties and permit the formation of clinging bubbles. These products are detergent-based.

Foam can also be made with bubble stabilizers derived from protein matter. These include chemical, protein, and flouro-protein foams. These foams have great bubble stability but do not share the wetting and penetrating characteristics of surfactant foams.

Wet Water

The basic form of surfactant-treated water for improved extinguishing efficiency is wet water. Wet water is defined as water to which a wetting agent has been added (NFPA 18). Wet water products first became available after the Second World War (Bryan, 1982). Wetting agent wet waters are approved by the United States Forest Service for use on decaying and charred Class A fuels only. Some wet waters will create a frothy wet water foam when mechanically agitated with air. These foams have rapid drain times and are used on bulk fuel fires. The National Fire Protection Association (1962) explained and demonstrated how wet water and wet water foams are more effective for fire suppression than plain water. Davis (1951) shows a wetting agent to be three times more effective than plain water on wood-burning fires.

The words "wet" and "wetting" are loosely used to mean penetrating and spreading. Wet water surfactants spread water by reducing surface tension. Textiles and other water porous materials can be wetted by this filming action of wet water. Detergent-based foaming agents not only spread the water, but also use a solvent to promote penetration through water-resistant plant surfaces.

Mechanical Foam

The largest type of treated water for fire suppression, mechanical foam, was first made in 1904. Detergent-based foaming agents for mechanical foams appeared in the 1930's (Bryan, 1982). Mechanical foams require a device to mix air with foam solution and allow for desired bubble expansion. Apparatus that provide these features include: 1) an aspirating nozzle with expansion tube, 2) an air compressor, pipe tee and length of hose or mixing chamber, and 3) turbo jet or water-agitating nozzle. Aspirating nozzles are almost universal. These nozzles use a venturi to pull air into the solution as the stream is being atomized into an expansion chamber. Foaming agent is usually mixed by eduction. Large water flow through these nozzles require large concentrate flow at the eductor. A deterrent, therefore, to most foam use is the large space required on an engine to carry sufficient agent for its task.

The compressed air foam system (Schlobohm and Rochna 1987) brings air and water together at equal pressures near the pump and compressor. With air in the hoselay, water flow is one-third less than without. Wildland foam agents are made at high concentration, and mix ratios are 1/10 - 1/20 of other foams, making agent storage space practical.

Recommended expansion ratios for mechanical foams range from 8 and 10 to 1 for wildland foams to 200 and 1000 to 1 for high and medium expansion foams. However, detergent, high and medium expansion, and wildland foams show very similar expansion characteristics for a given apparatus (Hubert). At a mix ratio of 0.3 percent, 1 gallon of wildland foaming agent can turn 300 gallons of water into 3000 gallons of foam.

Wildland Foam--As a relative newcomer to the mechanical foam group, wildland foam combines some of the best attributes of its cousins. Wildland foam retains the heat absorption of water and the spreading characteristics of a wetting agent. Like other detergent-based foams, wildland foam penetrates all Class A fuels. Its ability to cling to surfaces enables penetration, reflection of radiant heat, and suppression of oxygen. With other foams, wildland foam shares vapor suppressant and rapid flame knockdown capability. What wildland foams do not share with any other medium is performance per gallon of water. This is mainly because of the compressed air foam system (CAFS) attempted by Peterson and Tuve (1956), and revived by Ebarb (1978). Unlike aspirating nozzles, compressed air systems convert 90 percent of the water to foam. Systems of 40 cfm provide instant knockdown from 90 feet with 35 gallons per minute of water as foam.

Wildland Foam and the Compressed Air Foam System--With the compressed air foam system, wildland foams become a valuable tool for fighting fires in the wildland-urban interface. Water conservation is a key feature. A limited water supply cannot only be expanded, but because of the expansion, the water also becomes more effective. There are applications for both the firefighter who must drive to a distant water source, and the woodland homeowner who may have a finite water supply in a pond or pool. High agent concentrations and low mix ratios (3 gallons/1000) permit adequate on-board storage without reducing engine water capacity. Hoses, filled with foam, are light and maneuverable.

The clinging, wetting, and reflecting properties of wildland foam make exposure protection perhaps its most important application. Compressed air provides the discharge distance to reach and the agitation to cling to walls, eaves, roofs, and trees. Small, portable pumping systems can give the homeowner a method of on site structure protection.

Compressed air wildland foam may have applications for protection of residential fuel tanks. These foams have also been shown to be effective extinguishing small liquid fuel spill fires.

Another application for wildland foam with the compressed air system in the interface may be structure attack. Layman (1955) developed the indirect attack for structures using rapid, low water flows into superheated spaces and watched fires go out without entering buildings. On urban training fires over the past two years, the compressed air foam system has duplicated this feat.

CONCLUSION

Utilization of water for fire suppression has not changed over the centuries, with few exceptions. The fact is that use of any additive with water is the exception. AFFF and related film-forming foams occupy a small niche of specific duties on liquid fuel fires. Thickeners, such as retardants, are accepted for aerial use on wildfires large enough to justify expense, but development of new technologies, such as residential sprinklers, continues to be water oriented. Wildland and structure fires are primarily fought with plain water. And, although structure fire personnel rely on documented formulas for water use, wildland firefighters do not have a guide for water use.

Acceptance of water additives to improve efficiency will not occur overnight. The advocacy of surfactants in the literature for over 50 years and their continued limited use indicates a strong tradition of water use. This same advocacy would seem to necessitate justification of plain water, not surfactant. The integration of strategies and technologies of wildland and urban fire services may present the forum necessary for the social, political, and economic change from water to wet water and foam. Regardless of application or apparatus efficiency, water should never be used to fight fire without a surfactant.

REFERENCES

Bryan, John L. 1982. Fire Suppression and Detection Systems. 2d ed. New York: MacMillan Publishing Co. Inc. 518 p.

Davis, N. H. Jr. 1951. Wetting and Penetrating Agents. In: Proceedings 23d annual fire department instructors conference; Chicago: Insurance Services Office.

Ebarb, P. 1978. Texas snow job. Fire management notes. Washington, D.C.: U.S. Department of Agriculture, Forest Service, 39(3):3-5.

Grady, Clarence. 1987. [Personal communications]. November. Salem, Oregon: Chemeketa Community College.

Haessler, Walter M. 1974. The extinguishment of fire. Boston: National Fire Protection Association, 34 p.

Hubert, Mitch. 1987. [Personal Communication]. October 27, 1987. Marinette, Wisconsin: Ansul Fire Protection Company.

Insurance Services Office. c. 1980. Fire Supression Rating Schedule. New York: Insurance Services Office.

Layman, Lloyd. 1955. Attacking and Extinguishing Interior Fires. Boston: National Fire Protection Assocation. 149 p.

NFPA 18. 1979. Standard on Wetting Agents. Quincy, MA: National Fire Protection Association.

National Fire Protection Association. 1962. Fire Protection Handbook. 12th ed. Boston: National Fire Protection Association. 15(6):43-46.

Peterson, H.B., Tuve, R.L. 1956. Characterization of Foams for Fire Extinguishment. Industrial and engineering chemistry. 48(11):2024-2030.

Ratzer, A.F. 1956. History and Development of Foam as a Fire Medium. Industrial and engineering chemistry. 48(11)2012-2016.

Rios, Tom. 1987. [Personal Communication]. October 28. Boise, Idaho: U.S. Department of Interior, Bureau of Land Management, Boise Interagency Fire Center.

Schlobohm, Paul; Rochna, Ron. 1987. Foam as a Fire Suppressant: An Evaluation. In: Wildland Fire 2000 Symposium, April 1987; South Lake Tahoe, California. Berkeley, California: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

FOREST FIRE CLOSE TO HOME: TERRACE BAY FIRE #7/86

B. J. Stocks

ABSTRACT: Terrace Bay Fire #7/86 occurred on the afternoon of May 21, 1986 near the small pulpmill town of Terrace Bay, located on the north shore of Lake Superior 225 km east of Thunder Bay, Ontario. A persistent lack of precipitation, combined with strong winds, low humidity levels, dry ground vegetation, and low crown foliar moisture contents, resulted in extreme fire danger conditions in the Terrace Bay area. The fire crowned immediately, spread rapidly toward the town, and caused the hasty evacuation of 500 residents. Aggressive ground attack, with the support of five heavy water bombing aircraft and eight helicopters, stopped the forward progress of the fire at the edge of town. The final fire size reached 200 ha, but no building or property loss occurred.

INTRODUCTION

Since the advent of organized forest fire suppression in Ontario early in this century, tremendous strides have been made in the detection and control of wildfires. During the past decade an average of 91 percent of all fires have been contained at less than 4 ha in size. A glance at the landscape of northern Ontario, however, will attest to the fact that periodic large wildfires continue to be the dominant force in shaping forest composition in this area. An appreciation of this fact, and an understanding that severe wildfires can and will continue to occur intermittently in spite of modern and sophisticated fire management technology, is essential to residents of northern Ontario. The evacuation of numerous towns and villages and the destruction of many cottages and recreational facilities over the past 10-15 years have served to emphasize this fact dramatically.

This paper describes a relatively small (200 ha) fire that occurred adjacent to the town of Terrace Bay, located on the Trans-Canada Highway on the north shore of Lake Superior, 225 km east of Thunder Bay, Ontario. Terrace Bay is a typical northern Ontario pulpmill town with a population of approximately 3,000. Known as Terrace Bay Fire #7/86, this fire occurred on the afternoon of May 21, 1986 under conditions of extreme fire danger; it burned quickly through a forested area adjacent to Terrace Bay and reached the edge of the town before it was brought under control. Although fast and effective fire suppression activity prevented loss of property, the fire forced the temporary evacuation of 500 residents.

WEATHER AND FIRE DANGER RATINGS

Daily (1300 h local daylight time) weather observations recorded at the federal Atmospheric Environment Service (AES) weather station located at the Terrace Bay airport, approximately 3 km northwest of Terrace Bay Fire #7/86, are presented in table 1. The calculated fuel moisture codes and fire behavior indices of the Canadian Forest Fire Weather Index (FWI) System (Anon. 1984) are also shown in table 1 for the period between May 1 and May 21, the day on which the fire occurred. Despite relatively cool temperatures throughout May, the lack of precipitation during the two weeks prior to May 21, combined with high winds and low relative humidity levels during the five days immediately preceding the fire, resulted in extreme fire danger conditions on May 21. Fine Fuel Moisture Code (FFMC) and Initial Spread Index (ISI) levels were extreme (93 and 24, respectively) and this, in conjunction with a moderate Buildup Index (BUI) of 32, ensured that fires would ignite easily and spread very rapidly in the Terrace Bay area on the day of the fire.

Hourly weather observations from the Terrace Bay airport for the morning and afternoon of May 21 are shown in table 2. Temperatures were normal for the season but relative humidity values were quite low throughout the day; relative humidity dropped from 40 percent at 0800 h to 13 percent by 1600 h. Strong, gusty winds from the east-northeast prevailed during the afternoon, with average windspeeds of 25-30 km/h and gusts in excess of 40 km/h. The area was under the influence of a large ridge of high pressure centered 400 km north of Terrace Bay; skies were clear, and the atmosphere was unstable. Hourly weather observations confirmed the fact that weather and fuel moisture conditions were conducive to extreme fire behavior on May 21.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

B. J. Stocks is Head, Fire Research Unit, Great Lakes Forestry Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario, Canada.

Table 1--Daily 1300 h weather observations and calculated fuel moisture code and fire behavior indices of the Canadian Forest Fire Weather Index (FWI) system for the Terrace Bay Airport AES weather station

Date	Dry-bulb temp. (°C)	Relative humidity (%)	Wind velocity (km/h)	Wind direction (degrees)	Rain (mm)	FWI System components[a]					
						FFMC	DMC	DC	ISI	BUI	FWI
May 1	-4.3	22	26	20	0.0	87.3	6	17	10.8	6	9
2	0.4	75	11	10	0.0	84.0	6	20	3.2	7	3
3	9.5	23	19	350	2.3	77.7	7	24	2.4	8	2
4	5.6	93	7	170	0.0	77.0	7	27	1.2	8	1
5	6.4	93	28	90	1.3	65.4	7	31	2.2	9	2
6	12.2	63	22	120	12.4	49.6	4	17	0.5	5	0
7	6.7	67	22	30	0.0	66.9	5	20	1.7	6	1
8	11.8	34	19	90	0.0	82.6	7	25	4.0	8	4
9	12.0	63	15	160	0.2	83.4	8	29	3.6	10	4
10	10.9	67	9	150	0.0	83.5	9	34	2.7	11	3
11	14.8	36	15	150	0.0	87.7	12	39	6.6	14	8
12	8.4	94	9	140	0.0	79.8	12	43	1.8	14	2
13	7.2	80	9	130	0.0	79.9	13	46	1.8	15	2
14	15.1	53	13	180	0.0	84.2	15	52	3.7	17	5
15	12.8	89	9	160	0.0	80.6	15	56	1.9	18	3
16	13.8	75	13	230	0.0	81.4	16	61	2.6	19	4
17	14.2	43	20	230	0.0	86.1	18	66	6.8	22	11
18	12.2	44	24	30	0.0	86.9	20	71	9.2	24	14
19	11.0	27	22	90	0.0	89.5	23	75	12.0	26	18
20	15.6	18	20	70	0.0	92.5	26	80	16.8	29	24
21	17.8	20	26	70	0.0	93.0	30	86	24.2	32	33

[a] FFMC, Fine Fuel Moisture Code; a numerical rating of the moisture content of litter and other cured fine fuels. DMC; Duff Moisture Code, a numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. DC, Drought Code, a numerical rating of average moisture content of deep, compact, organic layers. ISI; Initial Spread Index, a numerical rating of the expected rate of fire spread (combines FFMC and wind). BUI; Buildup Index, a numerical rating of the total amount of fuel available for combustion (combines DMC and DC). FWI; Fire Weather Index, a numerical rating of fire intensity (combines ISI and BUI) that is used as a general index of fire danger.

FIRE ORIGIN AND BEHAVIOR

The first report of smoke from Terrace Bay Fire #7/86 was received at the Ontario Ministry of Natural Resources (OMNR) fire attack base in Terrace Bay at 1402 h on May 21; it described a fire approximately 2 km east of town alongside the Canadian Pacific Railway (CPR) tracks. Subsequent reports indicated a rapid increase in the amount of smoke visible from town, evidence that the fire was well established and spreading quickly. This seems reasonable in view of the strong winds and dry conditions that prevailed at that time; furthermore, ground vegetation had not yet flushed and crown foliar moisture content levels were at a springtime low.

Railway maintenance operations were under way along the CPR line east of Terrace Bay at the time the fire was reported; although there is strong evidence that people or actions associated with this operation were the cause of the fire, this point is being disputed by the CPR and the case is now before the Ontario provincial courts. However, an investigation of the fire perimeter along the south side of the CPR tracks indicated that the fire originated alongside the railway line, at

Table 2--Hourly weather observations recorded on May 21, 1986 at the Terrace Bay Airport by AES personnel

Local time	Dry-bulb temp. (°C)	Relative humidity (%)	Wind velocity (km/h)	Wind** direction (degrees)
0800	8	40	20	060
0900	11	32	18	060
1000	13	28	26 (37)***	060
1100	13	31	26 (37)	060
1200	17	24	29 (43)	080
1300	18	21	26 (37)	070
1400	19	18	26 (37)	070
1500*	--	--	--	---
1600	21	13	31 (46)	050
1700	21	14	23 (33)	050

*not recorded as a result of evacuation caused by Terrace Bay fire #7-86

**wind direction was estimated, as the direction recorder was not operable

*** maximum hourly gust

a point approximately 1.9 km east of the Terrace Bay highway overpass where the CPR line begins a 90° curve to the north (fig. 1). At this location small conifers immediately alongside the tracks exhibited minor fire damage, consistent with trees burned while the fire was in its initial, low-intensity phase. Southwest of the tracks, char heights on individual trees and tree clumps increased dramatically, and within 50-60 m of the tracks, full crown fire development had occurred. Visual observation by airborne OMNR fire control personnel assigned to Fire #7/86 supports this analysis of the fire's point of origin and direction of spread.

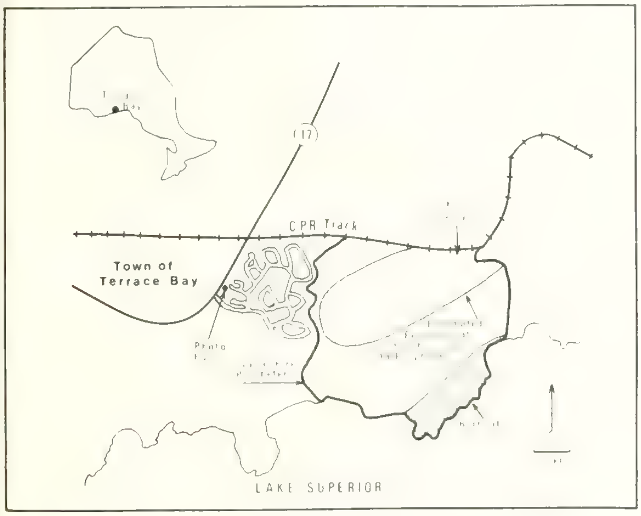

Figure 1--Location of Terrace Bay Fire #7/86 in relation to the town of Terrace Bay. Map shows the fire origin, estimated size and location at 1520 h on May 21, and the final fire perimeter.

Observers in helicopters and aircraft confirmed that the fire crowned and spread very quickly in a southwesterly direction. It reached the eastern edge of Terrace Bay at approximately 1520 h. If we assume that the fire was well established at the curve in the CPR line by 1410 h, then it spread a distance of 1.4 km in 70 minutes; this is equivalent to a forward rate of spread of 1.2 km/h. Tables and equations from the recently developed Canadian Forest Fire Behavior Prediction (FBP) System (Alexander et al. 1984, Lawson et al. 1985) allow us to predict the forward spread rates for Terrace Bay Fire' #7/86. Fuels in the fire area, primarily black spruce *(Picea mariana* [Mill.] B.S.P.) and white birch *(Betula papyrifera* Marsh.), were typical of the boreal mixedwood fuel type. For fuel type M-1 (Boreal Mixedwood - leafless) in the FBP System, a predicted spread rate of 1.26 km/h is obtained if we assume a 50 percent softwood/50 percent hardwood mixture and use the measured ISI of 24.2 (fig. 2). This compares favorably with the observed rate of spread on the afternoon of the fire. The FBP System also permits estimation of the shape and area of the fire at 1520 h. For a windspeed of 26 km/h and a forward spread rate of 1.26 km/h, a length: breadth ratio of 2.35 and a size of 67 ha at 1520 h is obtained. The estimated fire perimenter at that time is shown in figure 1.

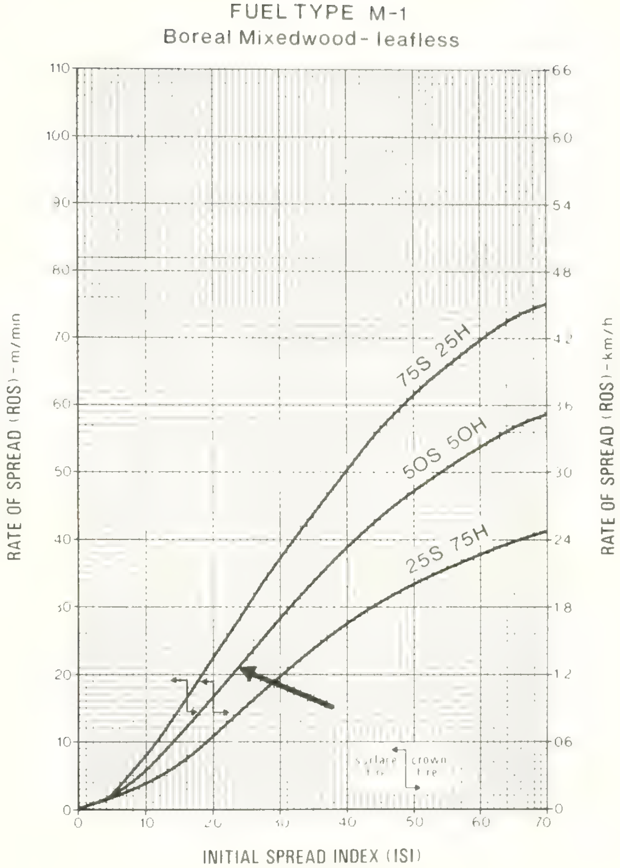

Figure 2--Rate of Spread / Initial Spread Index (ISI) graph for the Boreal Mixedwood (leafless) Fuel Type from the Canadian Forest Fire Behavior Prediction (FBP) System.

The final, almost-square shape of Terrace Bay Fire #7/86 was a function of the CPR tracks on the north side, a burnout operation from Lake Superior in the southeast corner, and suppression action on both the flanking and backing portions of the fire. The shape of the fire as it approached the eastern edge of Terrace Bay, as estimated according to the FBP System and confirmed by observers, was much more elliptical, which is typical of a fast-moving, wind-driven crown fire (Fig.1). Photographs taken from the town, which show the behavior of the oncoming fire, are presented in Figures 3 and 4.

SUPPRESSION AND EVACUATION ACTIVITY

Within moments of the reporting of Terrace Bay Fire #7/86, OMNR fire crews in the Terrace Bay area were dispatched to the fire, and air attack and helitack support were requested from the OMNR North Central Region Fire Centre in Thunder Bay. Heavy water-bombing aircraft were dispatched from bases in Geraldton, Armstrong, and Kapuskasing, and helitack units were sent from Thunder Bay, Geraldton, and Shebandowan. Because of the long distances involved some of this support arrived

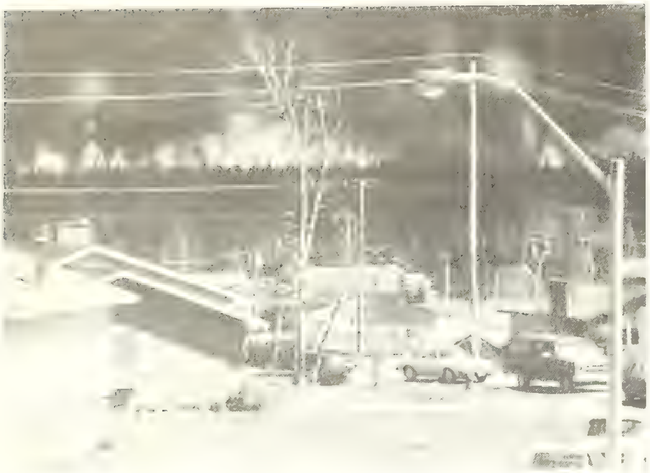

Figure 3--Evacuation from the eastern subdivision of Terrace Bay at approximately 1500 h as Fire #7/86 approaches (photo credit: Gary Gusul).

Figure 4--CL-215 waterbomber working on the southwestern edge of the fire at approximately 1515 h (photo credit: Gary Gusul).

after the head of the fire had reached the eastern subdivision of Terrace Bay. The forward progress of the fire was halted at this point, in part because of sparse fuels in the zone between the forested area and the subdivision, but primarily because of the highly effective use of water bombers (one CL-215 and two Canso PBY-5A's) and bucketing helicopters. The sparsely fueled buffer zone had not been deliberately created for protection purposes, but was the result of normal human activity in this area. As the fire approached, OMNR ground crews, with the support of municipal fire crews from Terrace Bay and the nearby town of Schreiber, were involved primarily in protecting properties in the parts of the subdivision that appeared most threatened. As additional support arrived it was used to control the flanks of the fire, suppress spot fires, bulldoze firebreaks, carry out a burnout operation from Lake Superior, and consolidate control lines. Although the fire was not brought under complete control until late in the evening of May 21, the threat to the town effectively ended when the main fire's run was halted. In all, a total of five heavy water bombing aircraft, eight helicopters, and eight OMNR fire crews worked on the fire.

As the fire approached the eastern subdivision of Terrace Bay, approximately 500 people were evacuated from 100 homes in that area and moved to other parts of the town. The evacuation notice was broadcast on local radio and by police just before 1500 h, and the relocation of people was prompt and orderly. Other residents in town, as well as the occupants of local businesses, schools, and hospitals, were placed on evacuation alert but were not relocated. People were allowed to return to their homes at 1900 h that night when the threat to the subdivision had subsided.

CONCLUSIONS

Terrace Bay Fire #7/86 underscored rather dramatically for the residents of Terrace Bay the very real danger and potentially catastrophic impact of forest fires on communities located in or close to forested areas. Under conditions of extreme fire danger, which are quite common in northern Ontario, particularly during the spring, fires can be ignited easily, can crown immediately, and can spread very quickly. That such fires will continue to occur is a foregone conclusion and it is unrealistic to expect that fire management agencies will always be able to respond as quickly and effectively as OMNR did in this case. Terrace Bay Fire #7/86 was detected very early, and water bombers that had been pre-positioned in areas of high fire danger were able to reach the fire very quickly. Once there, these aircraft worked in a coordinated and highly effective manner to halt the forward progress of the fire. A textbook operation such as this, in which everything went well, is not, however, something communities in forested areas should count on. It is essential that they comprehend the forest fire phenomenon fully, and work together to protect themselves and their communities. The people of Terrace Bay are at present working within their local Emergency Measures Organization to upgrade emergency communication and evacuation procedures, to create and maintain firebreaks around their community, and to work closely with OMNR to prevent future fires.

REFERENCES

Alexander, M.E.; Lawson, B.D.; Stocks, B.J.; Van Wagner, C.E. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim ed. Dep. Environ., Can. For. Serv., Fire Danger Group. 73 p. + supplements.

Anon. 1984. Tables for the Canadian Forest Fire Weather Index System. 4th ed. Dep. Environ., Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 25. 48 p.

Lawson, B.D.; Stocks B.J.; Alexander, M.E.; Van Wagner, C.E. 1985. A system for predicting fire behavior in Canadian forests. p. 6-16 *in* Proc. Eighth Conf. Fire and For. Meteorol. (29 April to 2 May 1985, Detroit, Mich.). Soc. Am. For., Bethesda, Md. SAF Publ. 85-04.

PROTECTING HOMES IN AUSTRALIA

Andrew A. G. Wilson

Four hundred fifty houses were surveyed after the 1983 Ash Wednesday fire at Mount Macedon, Australia. Houses were more likely to survive when:

- Fire intensity was low,
- Householders extinguished fires near the house,
- Roof material was tile or steel deck, rather than wood or corrugated iron,
- Roof pitch was low,
- Wall material was brick rather than wood,
- Objects such as sheds or wood-heaps were not present near the house, and
- Trees were not near the house.

The probability of house survival can be predicted using an equation. The equation and the research are described in the Journal of Environmental Management, Vol. 23, P. 259-270.

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Andrew Wilson is a researcher, Fire Protection Branch, Department of Conservation, Forests and Lands, G.P.O. Box 480, Melbourne, Victoria, Australia, 3001.

GUIDELINES FOR BURNING SPOTTED KNAPWEED INFESTATIONS FOR FIRE HAZARD REDUCTION IN WESTERN MONTANA

Gavriil Xanthopoulos

ABSTRACT: Spotted knapweed is a range weed that constitutes not only a grazing problem but also a serious fire hazard problem. Burning it efficiently for fire hazard reduction has proven difficult. Knapweed specific fuel models have been developed and guidelines are offered to help managers accomplish safe and effective prescribed burns.

INTRODUCTION

Spotted knapweed (Centaurea maculosa) is an introduced weed in the northwestern United States. It mainly invades dry sites with disturbed soil such as roadsides, trails, house yards, construction sites and overgrazed grasslands. In addition to causing grazing problems it constitutes a serious fire hazard problem.

The use of prescribed burning does not seem to be a promising control method for spotted knapweed because of its seed longevity. Burning spotted knapweed is attempted on many occasions, mainly in the spring, for fire hazard reduction purposes, around houses and other developments. Effective burns have proven difficult on many occasions, especially when fine grass fuels are not present, because fire does not carry through knapweed stems easily, under unfavorable conditions. On the other hand in some cases very intense fires have been observed in knapweed. The main reasons for this fire behavior are (Xanthopoulos 1986):

1. Extreme variation in spotted knapweed fuel loading between sites, and
2. Inclusion or not of standing knapweed stems as fuel available to the fire, depending on burning conditions.

FIRE BEHAVIOR MODELING

Existing stylized grass fuel models (models 1 and 3) (Anderson 1982) have been found to work poorly for spotted knapweed. To facilitate efforts to burn this weed regression equations allowing the calculation of fuel loading based on knapweed height and ground cover were developed and its characteristics as a fuel were determined (Xanthopoulos 1986). Fire modeling using these tools requires access to a fire behavior prediction system like BEHAVE (Burgan and Rothermel 1984) and can provide the user with accurate site specific predictions. In addition one can use fire behavior graphs that have been developed for three typical fuel beds of knapweed infestations, as burning guides without resorting to computer modeling (fig. 1-8).

The graphs have been developed for infestations of 30, 50 and 70 cm average standing knapweed height in western Montana, since height was found to correlate well with fuel loading. They have been developed for early spring burns, and do not include any live herbaceous fuel. If new spring growth is present, less intense behavior than predicted should be expected, or the fire will not carry at all. The graphs are valid if fine grasses are present with a canopy coverage of less than 40% (Xanthopoulos 1986).

The stylized spotted knapweed models were given numbers for easiest reference. Models 81 and 91 refer to 30 cm tall knapweed. Models 82 and 92 refer to 50 cm and models 83 and 93 to 70 cm tall infestations. Models 91, 92, 93 include both litter and standing knapweed loadings while the corresponding models 81, 82 and 83 include only litter. If the selection of the appropriate model is based on ocular estimation of standing knapweed, it should be noted that this estimate usually corresponds to the maximum height and should be reduced by approximately 30% (Burgan and Rothermel 1984). If the graphs for the eighty series models predict a flame length in the range 20-30 cm, fire should be expected to burn according to the ninety series models. Below the threshold of 20 cm flame length, fire will carry only in the litter according to the eighty series graphs, providing an incomplete burn.

The graphs are offered as guidelines to help the user select environmental conditions (wind, dead fuel moisture) that will allow safe and effective burns. The effect of slope can be combined with the effect of midflame windspeed, using the effective midflame windspeed graphs in figure 1 and 2 (Albini 1976). Fire modeling limitations, and loss of resolution by the use of stylized rather than site specific models should be realized. Care should be exercised in the application of these guidelines.

Paper presented at the Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West, Missoula, MT, October 6-8, 1987.

Gavriil Xanthopoulos is Research Assistant in Forest Fire Management, School of Forestry, University of Montana, Missoula, MT 59812. He studies in the United States on a scholarship from the Greek State Scholarship Foundation (IKY).

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REFERENCES

Albini, F. A. 1976. Estimating wildfire behavior and effects. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 92 p.

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 126 p.

Burgan, R. E.; Rothermel, R. C. 1984. BEHAVE: Fire behavior prediction and fuel modeling system - FUEL subsystem. Gen. Tech. Rep. INT-1 Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 126 p.

Xanthopoulos, G. P. 1986. A fuel model for fire behavior prediction in spotted knapweed (Centaurea maculosa L.) grasslands in western Montana. Missoula, MT: University of Montana. 100 p. Thesis.

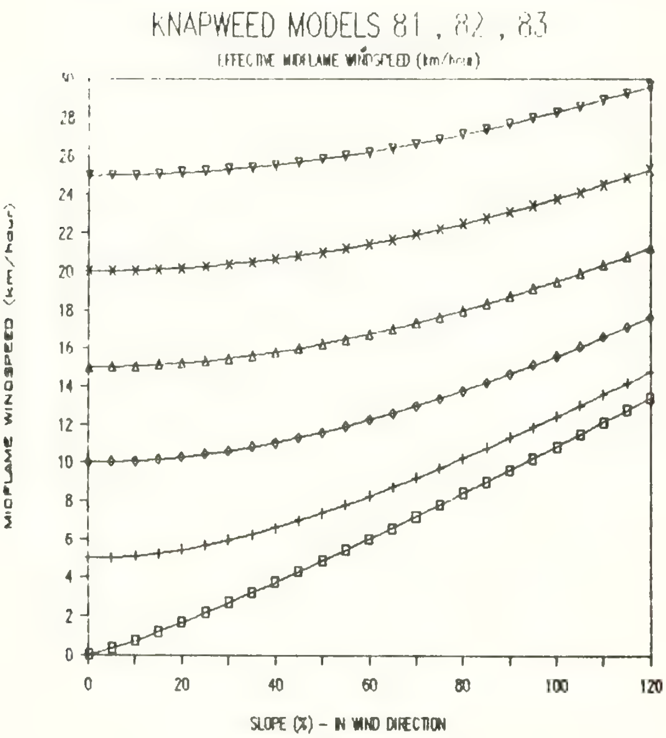

Figure 1--Effective midflame windspeed for fuel models 81, 82 and 83.

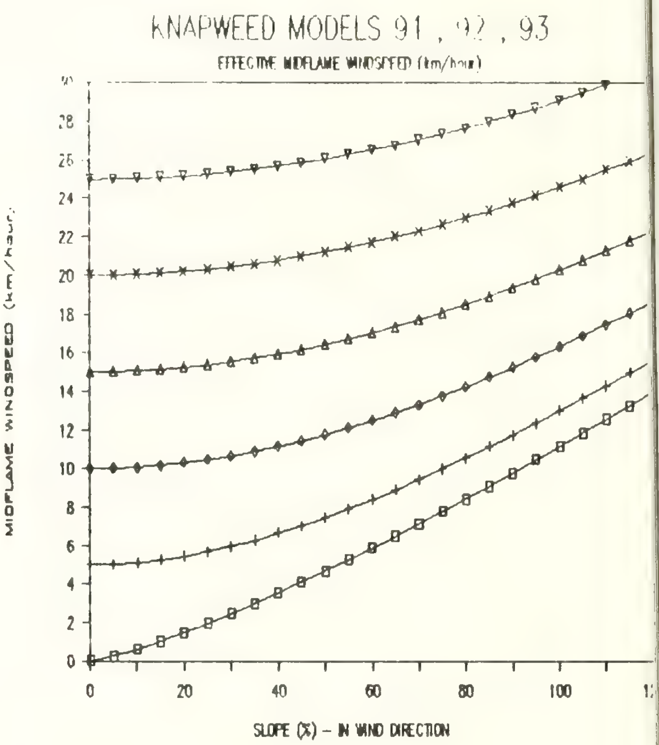

Figure 2--Effective midflame windspeed for fuel models 91, 92 and 93.

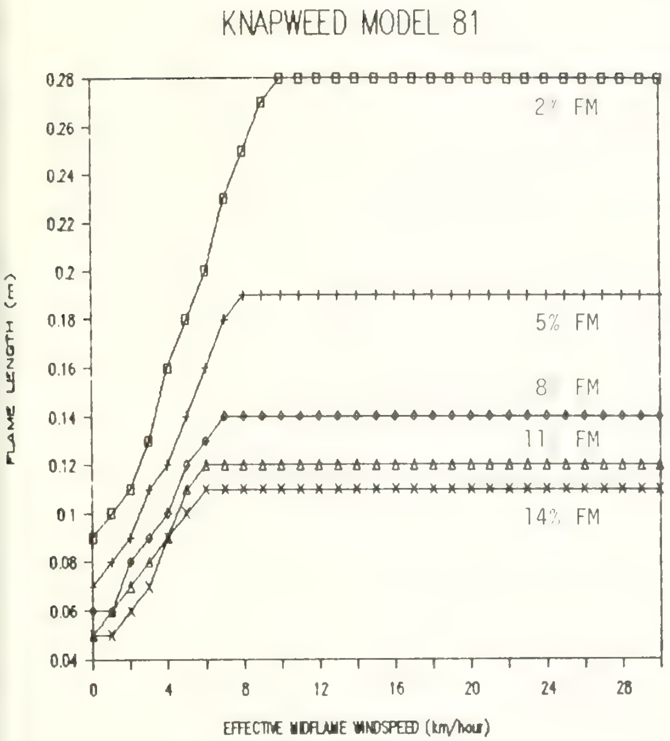

Figure 3--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 81.

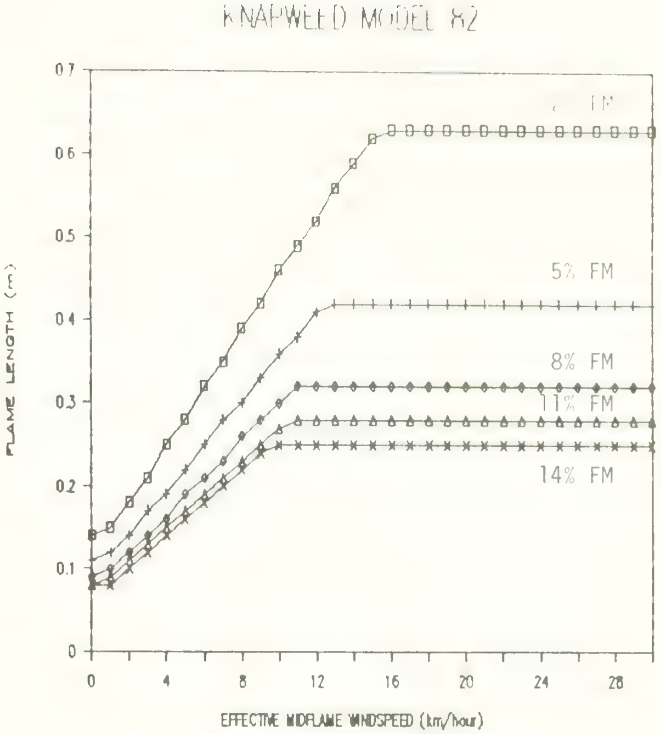

Figure 5--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 82.

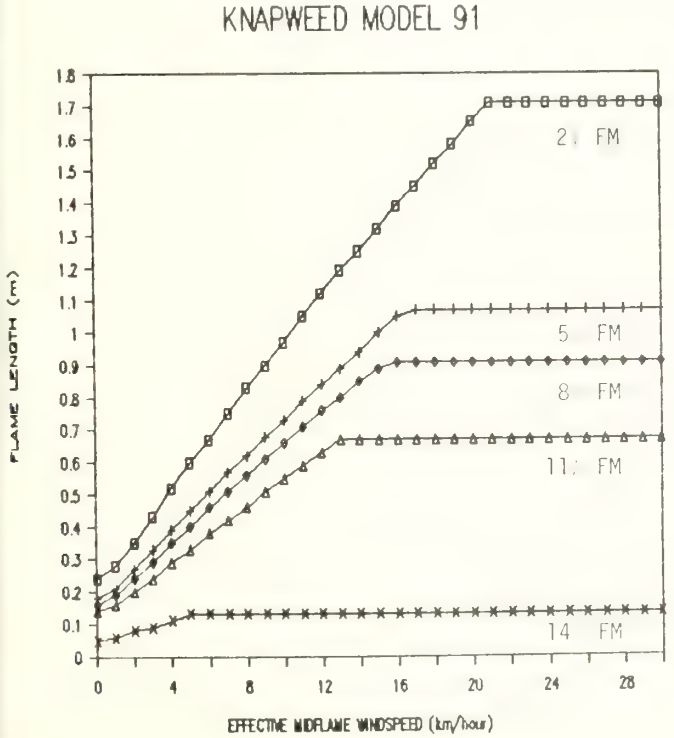

Figure 4--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 91.

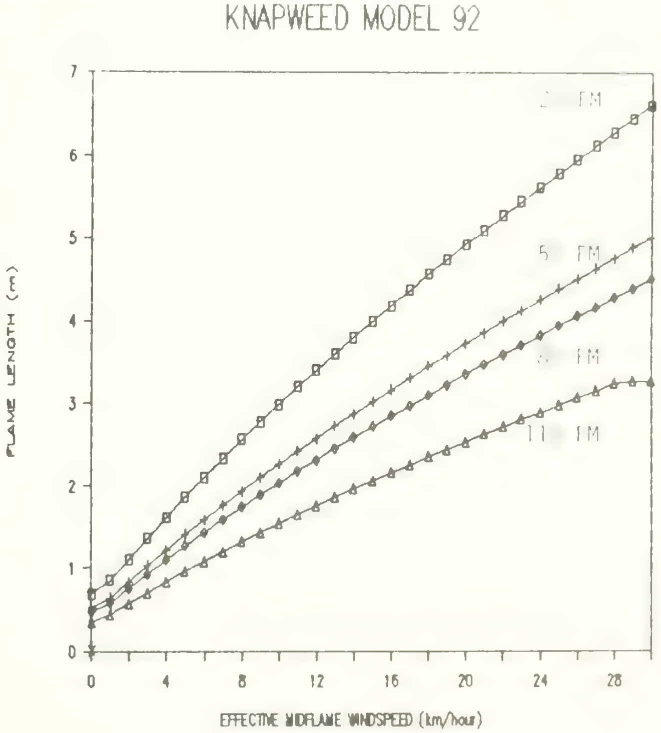

Figure 6--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 92.

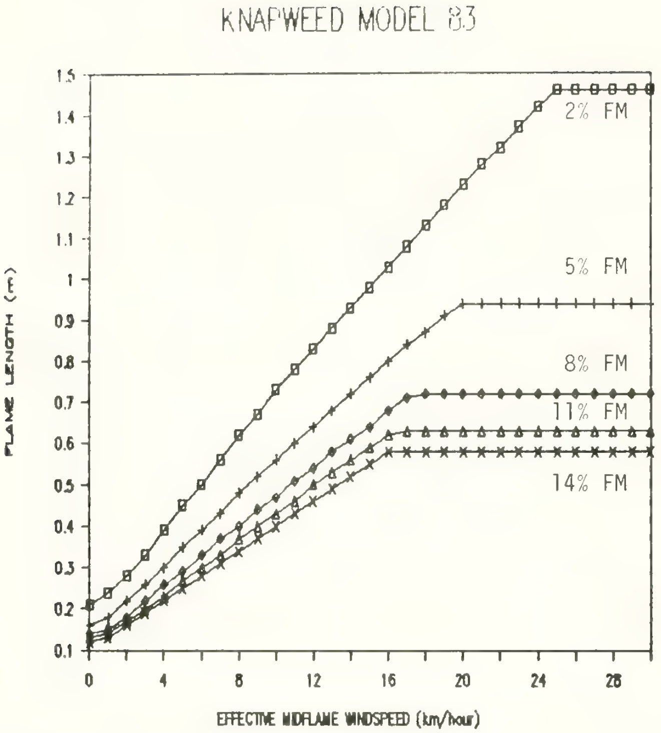

Figure 7--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 83.

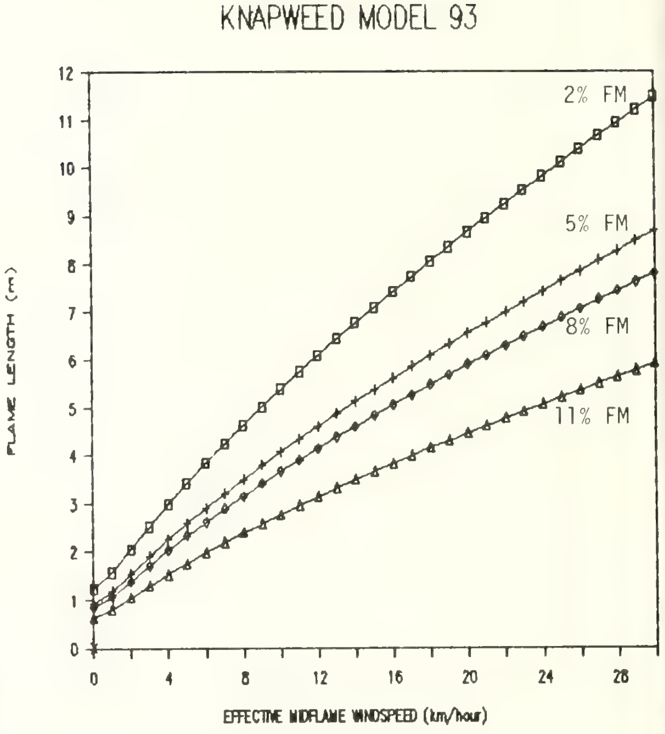

Figure 8--Predicted flame length (m) versus effective midflame windspeed (km/hour) for fuel model 93.

GREEK FOREST FIRES AND PROPERTY DAMAGE: A BRIEF HISTORY

Gavriil Xanthopoulos

ABSTRACT: Forest fires in Greece have historically burned 0.2% of the country's forest land each year. Property damages have been very small because of the use of non combustible materials in building construction. In recent years the percentage of area burned per year has nearly tripled and there have been significant losses of lives and property. This change is mainly the result of increased dead fuel availability and of the construction of houses within forest lands.

INTRODUCTION

Greece is a European country occupying an area of 130,875 km^2 in the southern Balkan Peninsula. Its population is 9,350,000 people. The climate is typically Mediterranean over most of the country, with warm-to-hot summers and mild winters.

Although more than half of the total land area is considered forest land, less than 20% is forested. The rest of the forest land is occupied by brushlands (maquis and Kermes Oak (Quercus coccifera) brushlands), open scrublands (phrygana) and grasslands. More than two-thirds of the forest belongs to the government.

Forest flammability is generally high. Most flammable types are the pine forests (Pinus halepensis, Pinus brutia) and the brushlands at the lower elevations, by the sea, in the middle and southern part of the country. Most of the population in recent years has concentrated in urban areas located near and expanding into these flammable forest types. Land value in these areas has become extremely high.

FOREST FIRES

Forest fires are very common in Greece every summer and early fall. Some of the worst wildfires happen in the low elevation pine forests which usually have a brush understory. They start as surface fires which frequently become fierce crown fires that defy all firefighting efforts. Crown fires most commonly remain coupled to the surface fire, although independently moving crown fires have also been observed (Kailidis 1981, Kailidis and Pantelis 1982). Surface fires in open brushlands are usually easier to control.

Long term statistics show that until 1976 about 0.2% of the tall forest and 0.2% of the grazing lands (brushlands and grasslands), burned every year (Kailidis 1981). In the last 15 years this percentage has nearly tripled. In the extremely dry year of 1985, 1.35% of the total forest land burned (Kailidis & others 1987). This is true in spite of the vast improvements in firefighting equipment in the last two decades. Only 5.3% of the total number of fires burn an area larger than 100 Ha, but in total they contribute about 72.5% of the area burned per year.

The reasons for the increase in number of fires and area burned are as follows (Kailidis & others 1987).

1. Decreased demand for fuel wood, following the urbanization of the people, has resulted in a 2-4 times increase of the available dead fuel on the ground during the last 30 years.
2. Less grazing has resulted in more fine fuels available to the fire.
3. A change of attitude of the people, who, contrary to the past, have become unwilling to help in firefighting, leaving it to the professionals.
4. A sharp increase of land value, especially close to cities and to sea shores where people build their summer houses. Arsonists use fire to destroy the forest because the Forest Law has strict provisions for building within a forest. Land ownership disputes between individuals and the state still exist.
5. An increase in number of visitors to the low elevation forests as more cars are available, and people spend more time in outdoor activities. In addition, the number of tourists visiting the country each year has increased sharply.
6. Political instability which has been shown to coincide with bad fire years.

PROPERTY DAMAGE

Literature on property damage resulting from wildfires, other than the burned forest itself, is scarce (Kailidis 1981). Three deaths and 300 people injured resulted from a 3,000 Ha wildfire in 1916 in a Pinus halepensis forest near Athens

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Gavriil Xanthopoulos is Research Assistant in Forest Fire Management, School of Forestry, University of Montana, Missoula, MT., 59812. He studies in the United States on a scholarship from the Greek State Scholarship Foundation (IKY).

belonging to the crown. The summer palace and other buildings were also destroyed in that fire. Since then and until a fierce crown fire in Athens (8/4/1981), only few small, temporary, mostly wooden, country buildings used by woodsmen and shepherds are known to have burned in forest fires. No more lives were lost until 1977.

As the forest fire situation became worse in Greece in recent years, more deaths have resulted from fires, mostly during fire suppression operations.

The 1981 fire in the northern suburbs of Athens, where houses had been built adjacent to or inside pine forests, resulted in significant property losses. In addition to tens of houses, cars, warehouses and other smaller buildings were destroyed. The houses burned between 2 and 3 pm under severe fire weather conditions (temperature 33-34°C, relative humidity 12%, and wind at 35 km/hr) which resulted in an independently moving crown fire (Kailidis 1981).

Severe forest fires in subsequent years have resulted in a few individual buildings adjacent to forests being burned, but not in the widespread fashion of the fire in Athens.

DISCUSSION

The vast majority of houses in Greece are traditionally built with non combustible materials (brick, concrete, clay tile roofs). Many villages have traditionally been built on steep slope terrain surrounded by forest or brushlands. In spite of this fact no major housing losses have resulted from historic wildfires in the past. This can be attributed both to the materials used in the construction of the houses and to the reduced amounts of dead fuels close to villages as a result of fuelwood collection and heavy grazing.

People nowdays choose to build their homes in the same ways using the same materials as in the past guided by tradition, availability of materials and common sense. There is no law requiring them to use these specific materials. In spite of this, even these houses can burn under extreme wildfire conditions. It should be noted though that the houses that burned on the large 1981 fire were between similar ones that did not burn although the fire reached their walls and roofs. It is speculated that windows may have been left open and that pine needles had accumulated on the roofs (Kailidis 1981). Another explanation may be that intense radiation from burning crowns may have ignited the curtains or other flammable materials inside these buildings.

The increase in area burned by a few large wildfires in recent years and the increase in life and property losses, in spite of the improved firefighting capabilities can be mainly attributed to the increase of available fuels. Regardless of materials and design, the presence of trees, shrubs, dead wood and needle litter close to a forest home, make it a candidate for burning. One can speculate that the 1916 destruction of the palace and the loss of lives probably took place in the only forest in the country at the time, in which fuelwood collection was not permitted.

REFERENCES

Kailidis, D. S. 1981. Iloriki, meros proto, dasikes pirkagies. Forest protection, part one, forest fires. 2d ed. Thessaloniki, Greece: Aristotelian University of Thessaloniki: 421 p.

Kailidis, D. S.; Markalas S.; Pantelis, D. 1987. 1985 i pio katastreptiki hronia dasikon pirkagion stin Ellada kai ston ipolipo kosmo. 1985 the most disastrous year of forest fires in Greece and the rest of the world. Thessaloniki, Greece: Laboratory of Forest protection, Aristotelian University of Thessaloniki: 39 p.

Kailidis, D. S.; Pantelis, D. 1982. 1981, hronia eklogon kai ton pio katastrofikon pirkagion ton dason ta teleutaia 60 hronia. 1981, a year of elections and most destructive forest fires in the last 60 years in Greece. Thessaloniki, Greece: Aristotelian University of Thessaloniki, Scientific Records of the School of Forestry and Natural Environment. 25(9): 315-348.

LIST OF ATTENDEES

K. R. Adams
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Ted Adams
Univ. of California
Agronomy Extension,
Davis, CA 95616

Dave Aldrich
ID Panhandle NF
1201 Ironwood Drive
Coeur d'Alene, ID 83814

Martin E. Alexander
Canadian Forestry Service
5320-122 Street
Edmonton, Alberta T6H 355

Pete Anderson
Resource Concepts, Inc.
340 N. Minnesota Street
Carson City, NV 89703

Hal Anderson
IFSL, Forest Service
P.O. Box 8089
Missoula, MT 59807

Larry Anderson
Kaibab National Forest
Williams Ranger District
Williams, AZ 86046

Patricia L. Andrews
USDA Forest Service
P.O. Box 8089
Missoula, MT 59803

Stephen F. Arno
Intermountain Research Station
P.O. Box 8089
Missoula, MT 59807

Jim Arthur
USFS
P.O. Box 7669, Federal Building
Missoula, MT 59807

Dick Bacon
Washington, D.C.

Dan Bailey
Missoula & Seeley Lake RD
5115 Highway 93 South
Missoula, MT 59801

Honorable Norman Bangerter
Chairman of the Western Governors
Conference

Mark R. Baron
North Kaibab Ranger District
P.O. Box 248
Fredonia, AZ 86022

George Bateman
Pocatello Fire Department
408 E. Whitman
Pocatello, ID 83201

Dennis Beeler
Spokane, WA

D. Behrens
State Forestry
1624 W. Adams
Phoeniz, AZ 85007

Stan Benes
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Walter Bennett
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Neil Benson
USFS--Ashland RD
645 Washington Street
Ashland, OR 97520

Bob Berney
Oregon State Fire Marshal
2150 NE Studio Road
Bend, OR 97701

Bill Berrigan
Washington Department of Nat Res
P.O. Box 190
Colville, WA 99114

Lynn R. Biddison
Chemonics Fire-Trol
39 Beaufort Harbor
Alameda, CA 94501

Elaine M. Bild
University of California, Berkeley
2223 Fulton Street, 4th Floor
Berkeley, CA 94720

Roger Binne
Department of Renewable Resources
Government of the Northwest Territ
Inuvik, NWT Canada XOE OTO

Argus Black
Beaverhead NF--Dillon RD
610 N. Montana Street
Dillon, MT 59725

Dave Blakely
Intermountain Research Station
P.O. Box 8089
Missoula, MT 59807

Ray Blehm, Jr.
MT Dept. of Justice, Fire Marshal
303 North Roberts, Room 371
Helena, MT 59620

Owen Bolster
Alberta Forest Service
Box 7040, Rostal Station M
Edmonton, Alberta Canada

Byron Bonney
U. S. Forest Service--Helena NF
Box 219
Lincoln, MT 59639

Tom Borden
American Forestry Association
1501 Richard Lake Road
Fort Collins, CO 80524

Donna Bornstad-Neer
Clinton Rural Fire District
Box 237
Clinton, MT 59825

Al Borup
Boise Interagency Fire Center
3905 Vista Avenue
Boise, ID 83705

Robert Bosworth
Idaho Panhandle National Forests
1201 Ironwood Drive
Coeur d'Alene, ID 83814

Herminio Da Silva Botelho
University of Idaho
Park Village Apartments, No. 36
Moscow, ID 83843

Francis D. Boule
Seeley Lake Fire District
P.O. Box 309
Seeley Lake, MT 59868

Bill Boyse
WA State Department of Natural Res
4224 6th Avenue SE, Building 1
Lacey, WA 98503

Dorothy Bradley
919 West Lamme
Bozeman, MT 59715

Bill Bradshaw
USDAFS
4955 Canyon Crest Drive
Riverside, CA 92507

Clyde Bragdon
U. S. Fire Administration
16825 South Seton Avenue
Emmitsburg, MD 21727

Jim Brain
Mt. Baker National Forest
1022 First Avenue
Seattle, WA

Juliette E. Brewer
USFS, Lakeside Ranger District
R. Rte. 3 Box B-50
Lakeside, AZ 85938

Jo Bridges
San Bernardino National Forest
1824 S Commercecenter Circle
San Bernardino, CA

George Brooks
U. S. Forest Service, R8
1720 Peachtree Road, N.W.
Atlanta, GA 30088

Gary Brown
Department of State Lands
2705 Spurgin Road
Missoula, MT 59801

Norman C. Brown
U.S. Fish & Wildlife Service
Star Route West, Box 386
Necedan, WI 54646

James K. Brown
Intermountain Fire Sciences Lab
P.O. Box 8089
Missoula, MT 59807

Edgar Brown
Chalender Ranger District
501 W. Bill Williams Avenue
Williams, AZ 86046

Albert Brown
USDAFS, Pacific Northwest Region
P.O. Box 3623
Portland, OR 97208

Kevin Brown
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Frank Bruno
USFS
Elk City Ranger Station
Elk City, ID 83525

Rollo H. Brunson
Dixie National Forest
82 North 100 East
Cedar City, UT 84720

Bruce Bugbee
619 Southwest Higgins, Suite P
Missoula, MT 59803

Jerry Buhre
Montana Department of State Lands
P.O. Box 1021
Lewistown, MT 59457

Chuck Bushey
Montana Prescribed Fire Services
P.O. Box 2101
Missoula, MT 59806

Wayne Bushnell
USDA Forest Service, Targhee NF
P.O. Box 20
Island Park, ID 83429

Dean Byrne
Bitterroot National Forest
316 N. Third
Hamilton, MT 59840

Sam Caliva
Bureau of Land Management
1717 Fabry Road, SE
Salem, OR 97306

John M. Carey, Jr.
USDA Forest Service
Route 3, Box 244
Cass Lake, MN 56633

William B. Carleton
Bureau of Land Management
E 4217 Main Avenue
Spokane, WA 99202

R. C. Carroll
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Kenneth Cassutt
State of New Mexico
P.O. Drawer 1508
Santa Fe, NM 87504

Bob Cavanagh
Reno Fire Department
200 Evans
Reno, NV 89501

Rod Chaffee
U.S.D.A. Forest Service
3502 Highway 30
LaGrande, OR 97850

Jack E. Chamberlain
Worley Fire District
P.O. Box 187
Worley, ID 83876

Grant F. Chandler
Fremont County
220 E. Main Street
St. Anthony, ID 83445

Debbie Chandler
Grande Ronde Fire Prevention Corp.
Route 4, Box 4190
La Grande, OR 97850

Jerry Chapman
USDI--Bureau of Land Management
P.O. Box 940
Miles City, MT 59301-0940

R. Gregg Chappell
Federal Emergency Management Avency
500 C Street SW, Room 714
Washington, DC 20472

Harry Chappell
USFS, Tahoe NF
11543 Via Vista
Nevada City, CA 95959

George I. Chesley
Deschutes NF, Ft. Rock RD
1645 Highway 20 East
Bend, OR 97701

Gerald F. Christian
Salmon Bureau of Land Management
P.O. Box 430
Salmon, ID 83467

Margaret Clark
Montana Department of Commerce
Cogswele Building, Room C211
Helena, MT 59601

Larry Clawson
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

Elizabeth Close
Intermountain Research Station
324 25th Street
Ogden, UT 84401

Boyd W. Carpenter
USFS, Caribou National Forest
Suite 230, Federal Building
Pocatello, ID 83201

Kelly Close
1353 "B" Dickinson
Missoula, MT 59812

Frank T. Cole
U. S. Fish & Wildlife Service
BIFC, 3905 Vista Avenue
Boise, ID 83705

Albert M. Comly
Curtis, Cox, Kennerly
327 North 17th Street
Philadelphia, PA 19103

Douglas E. Cook
Pennington County, SD Commission
22 Main Street
Rapid City, SD 57701

Richard Cooper
WA State Department of Natural Res
919 North Township
Sedro Woolley, WA 98284

James Costamagna
Forestry Div. Montana DSL
2705 Spurgin Road
Missoula, MT 59801

Bruce Coulter
Colorado State Forest Service
1504 Quaker Street
Golden, CO 80401

Bill Cowin
Idaho Department of Lands
1806 Main Avenue
St. Maries, ID 83861

Jack Cullen
U. S. Forest Service
2201 White Boulevard
Butte, MT 59701

Wes Culp
WA State Department of Natural Res
Route 1, Box 1375
Forks, WA 98331

Dan Curd
Bureau of Indian Affairs
Box 389
Well Pinit, WA 99040

Ronald G.O. Curtiss
U. S. Forest Service
12557 Highway #37
Libby, MT 59923

Dr. M. Rupert Cutler
Population-Environment Balance
1325 G. Street, NW, Suite 1003
Washington, DC 20005-3104

David Dacquisto
NAHB, Research Foundation, Inc.
400 Prince George Center Boulevard
Upper Marlboro, MD 20772-8731

Jerry Daffern
Western Fire Equipment Company
10835 W 39th Place
Wheat Ridge, CO 80033

Gladys Daines
USFS, Smokey Bear Program
Washington, D.C.

Gary Dakin
Alberta FS, Athabasca Forest
168 Airport Road
Fort Momurrey, Alberta Canada

Orville Daniels
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Mike Dannenbers
Missoula Rural Fire District
2521 South Avenue West
Missoula, MT 59801

Russ Davis
BIA-BAO
316 N. 26th Street
Billings, MT 59101

James Davis
U. S. Forest Service, Riverside Fire L
1106 LeConte Drive
Riverside, CA 92507

Bill De Groot
Canadian Forestry Service
101-15 Street, East
Prince Albert, Sask S6V 1G1

Mike De Grosky
Montana Department of State Lands
P.O. Box 490
Kalispell, MT 59901

Frank C. Dennis
Colorado State Forestry Service
1504 Quaker Street
Golden, CO 80401

Betty G. DeVeny
Salmon River Rural Fire District
P.O. Box 444
Riggins, ID 83549

Walter "Mick" DeZell
Bitterroot National Forest
316 North Third Street
Hamilton, MT 59840

Don Dowdell
WA State Department of Natural Res
1405 Rush Road
Chehalis, WA 98532

Judith L. Downing
Shasta-Trinity National Forest
914 Yosemite Drive
Chico, CA 95928

F. Wm. Driscoll
East Fork Fire District
P.O. Box 218
Minden, NV 89423

Richard L. Dudley
Clearwater National Forest
12730 Highway 12
Orofino, ID 83544

Dale Dufour
USFS
Missoula, MT 59801

Ann Mary Dussault
Missoula County
Courthouse
Missoula, MT 59801

Steve Eckert
USDI--Bureau of Land Management
P.O. Box 940
Miles City, MT 59301-0940

Peter Efroymson
Missoula Rural Fire District
2901 Ashby Street
Las Vegas, NV 89102

James Eggleston
U. S. Forest Service, Alaska Region
201 E. 9th Avenue, Suite 206
Anchorage, AK 99501

Bruce Eich
State Farm Insurance
2038 Overland Avenue, N.E.
Billilngs, MT 59104

Loren E. Enstad
North Lake Tahoe Fire Protection
P.O. Box 385
Crystal Bay, NV 89402

Ray Erickson
Florence Volunteer Fire Department
Florence, MT 59833

Jerry Fiman
USFS
West Fork RD
Darby, MT 59829

William C. Fischer
Intermountain Research Station
P.O. Box 8089
Missoula, MT 59807

Bill Fischer
Montana Department of State Lands
P.O. Box 490
Kalispell, MT 59901

Joe Flett
Spokane Tribe
Well Pinit, WA 99040

Lou Foley
Alberta FS, Provincial Forest Fire
P.O. Box 7040, Stn. M.
Edmonton, Alberta T5E 5S9

Jerry Foster
I.S.O.
Commercial Risk Services
Parsippany, NJ 07054

Gerald A. Fox
Kananaskis Fire Department
Box 280 Canmore
Alberta, Canada

William H. Frandsen
IFSL
P.O. Box 8089
Missoula, MT 59803

Nick Galan
Department of Renewable Resources
P.O. Box 130
Norman Wells, NWT Canada X0E 0V0

Joe Gasvoda
Forestry Div. Montana DSL
2705 Spurgin Road
Missoula, MT 59801

Steve Gauger
USFS
Box 116
Fortine, MT 59918

Guy L. Gettle
Foresight Engineering
134 Journey's End
Walnut Creek, CA 94595

Susan Giannettino
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Theron Gibson
Pierce Co. Fire District No.22
3206 W Tapps Drive E
Sumner, WA 98390

Charles Gibson
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

Jim Gilligan
Simplex
13340 NE Whitaker Way
Portland, OR 97230

Robert Gilrein
Bureau of Indian Affairs
P.O. Box 389
Well Pinit, WA 99040

Kevin Glanz
Frenchtown Rural Vol. Fire Dept.
Box 119
Frenchtown, MT 59834

Dennis Gordon
Bitterroot National Forest
316 N. Third
Hamilton, MT 59840

Dick Gormley
Douglas County Fire District
P.O. Box 96
Waterville, WA 98858

Glen Gray
Montana Department of State Lands
P.O. Box 490
Kalispell, MT 59901

Jim Greene
Department of State Lands
8001 North Montana Avenue
Helena, MT 59601

Guy Groves
Jefferson County
1700 Arapahoe Street
Golden, CO 80419

Lou Gugliotta
Jackson County Fire District No. 3
8333 Agate Road
White City, OR 97503

Jack Gustafson
USFS Cass Lake RD, Chippewa NF
Route 3, Box 219
Cass Lake, MN 56633

Jamie Haines
National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Dave Halverson
SD State Division of Forestry
Box 82
Custer, SD 57730

John Haney
Callatin NF, Hebgen Lake RD
P.O. Box 520
West Yellowstone, MT 59758

Michael Harrington
Intermountain Fire Science Lab
P.O. Box 8089
Missoula, MT 59807

H. B. Harryman
State of South Dakota
118 W. Capital
Pierre, SD 57501

Denis Hart
USDA Forest Service
20C1 Poplar
Helena, MT 59601

Roberta Hartford
University of Montana
Home Address: 16505 Folsom Road
Florence, MT 59833

Arnold F. Hartigan
Boise Interagency Fire Center
3905 Vista Avenue
Boise, ID 83705

Arvid B. Haugen
Wisconsin Department of Natural Res
3432 28th Street South
Wisconsin Rapids, WI 54494

Thomas P. Hawkins
Idaho Department of Lands
3706 Industrial Avenue, South
Coeur d'Alene, ID 83814

Ed Heilman
USFS--Retired
112 Michelle Court
Missoula, MT 59803

Don Henderson
Resource Concepts, Inc.
340 N. Minnesota Street
Carson City, NV 89703

Ernie Hendricks
USDA Soil Conservation Service
185 Camarillo Way
Twin Falls, ID 83301

Ron Hendrickson
USDA--Fire Management
P.O. Box 7669
Missoula, MT 59807

Steve Herbaly
Flathead Regional Development
723 5th Avenue, East
Kalispell, MT 59901

Ross Hesseltin
Spokane County Fire District
N 10003 Division, Suite 100
Spokane, WA 99218

Greg R. Heule
N. E. Teller Co. Fire Prot. Dst.
P.O. Box 5587
Woodland Park, CO 80863

William (Barry) Hicks
Beaverhead NF--Dillon RD
610 N. Montana Street
Dillon, MT 59725

Dan Hinckley
Keep Washington Green
Anderson Hall, UW
Seattle, WA 98195

Lenny Hinman
U. S. Forest Service
P.O. Box 531
Darby, MT 59829

Dick Hodge
U.S. Forest Service
Route 2, Box 4
Potlatch, ID 83855

Ron Hodgson
California State University
RECR & Parks Management
Chico, CA 59529-0560

Geoff Hogander
Bureau of Land Management
940 Lincoln Road
Idaho Falls, ID 83401

Steve Holden
Montana Department of State Lands
2705 Spurgin Road
Missoula, MT 59801

Jospeph T. Holland III
National Forest Products
533 Seabreeze Boulevard
Daytona Beach, FL 32018

Fred Holmes
Montana Department of State Lands
P.O. Box 490
Kalispell, MT 59901

Todd R. Holzwarth
East Grand Fire Prot. Dist. No. 4
P.O. Box 3030
Winter Park, CO 80482

Richard Homann
South Dakota Division of Forestry
HC 37 Box 604
Lead, SD 57754

Ken Hoover
WA State Department of Natural Res
4224 6th Avenue SE, Building 1
Lacey, WA 98503

Beth Horn
USDAFS
P.O. Box 7669
Missoula, MT 59807

Jim Hulbert
U. S. Forest Service
P.O. Box 703
Twisp, WA 98856

Donald L. Hunt
Spokane County Fire District
East 12100 Palouse Highway
Valleyford, WA 99036

Tom Ingersoll
U. S. Forest Service
798 N. Main Street
Bishop, CA 93514

Dale Jablonski
Utah Division of State Lands
152 East 100 North
Vernal, UT 84078

John Jackson
Oregon State Forestry Department
Route 2, Box 375
Prineville, OR 97754

Lawrence Jacobsen
Nevada Legislature
P.O. Box 367
Minden, NV 89423

Ed Jacoby, Jr.
New York State Dept. of Env. Cons.
50 Wolf Road, Room 408
Albany, NY 12233

Paula Jacques
Missoula Office of Community Devel
201 W. Spruce Street
Missoula, MT 59802

Phil James
U. S. Forest Service
P.O. Box 931
Newcastle, WY 82701

Dale Jarrell
Sawtooth National Forest
2647 Kimberly Road, East
Twin Falls, ID 83301

Lou Jekel
Rural/Metro Corporation
4323 N. Brown Avenue
Scottsdale, AZ 85251

Michael J. Jenkins
Department of Forest Resources
Utah State University
Logan, UT

Lynn Johnson
Florence Fire Department
Box 24
Florence, MT 59833

Cecelia Johnson
Intermountain Research Station
P.O. Box 8089
Missoula, MT 59807

Russ Johnson
San Bernardino NF
1824 Commercenter Circle
San Bernardino, CA 92408

Cameron M. Johnston
Intermountain Fire Sciences Lab
P.O. Box 8089
Missoula, MT 59807

Don Jones
Pocatello Fire Department
408 E. Whitman
Pocatello, ID 83201

Danny Jones
USDA Forest Service
30330 Watts Valley Road
Tollhouse, CA 93667

Chuck Jourden
USFS, Region 3
517 Gold Avenue
Albuquerque, NM

William Kaage
School of Forestry
Missoula, MT 59812

Steve Karkanen
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Nick Kaufman
2305 Quail Drive
Missoula, MT 59803

Ed Kautz
USDA Forest Service
310 W. Wisconsin Avenue
Milwaukee, WI 53203

Dennis Kennedy
USDAFS
Box W
Columbia Falls, MT 59912

Peter Kenney
Board of Commissioners
P.O. Box 2000
Georgetown, CO 80444

Paul Kraft
Dept. Renewable Resources
Box 240
Fort Simpson, NWT XOE ONO

Charlene Krager
USDA Forest Service
27812 Tiller Trail Highway
Tiller, OR 97484

John D. Krebs
Clearwater National Forest
12730 Highway 12
Orofino, ID 83544

Robert Krepps
Helena National Forest
301 S. Park, Drawer 10014
Helena, MT 59626

Margaret Krull
Siskiyou National Forest, I.V. RD
26568 Redwood Highway
Cave Junction, OR 97523

James W. Kunkel
KSU--State & Ext. Forestry
2610 Claflin Road
Manhattan, KS 66502

Darrell Kurk
Department of State Lands
P.O. Box 4126
Bozeman, MT 59772-4126

Troy Kurth
USFS, R-1
P.O. Box 7669
Missoula, MT 59807

Marshall Kyle
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

Mark Labhart
Oregon State Forestry Department
5286 Table Rock Road
Central Pt., OR 97502

Gene LaBlanc
Truckee Meadows Fire Department
10 Kerman Avenue
Reno, NV 89502

Kerry L. Lackey
U. S. Forest Service
P.O. Box 208
Crescent, OR 97733

Lee Lafferty
Oregon State Department of Forestry
2600 State Street
Salem, OR 97310

Suzanne Lagoni
Max Baucus
Senate Hart Building, SH-706
Washington, DC 20510

Wendy Lambson
Florence Fire Department
Box 24
Florence, MT 59833

Dennis Lamun
BIFC-BLM
11996 Demeyer
Boise, ID 83704

Laurence E. Lassen
USFS, Intermountain Research Station
324 25th Street
Ogden, UT 84401

Buck Latapie
U.S.D.A. Forest Service
1645 N E Highway 20
Bend, OR 97701

Steve Laursen
Montana Cooperative Extension Serv
School of Forestry, Univ of Montana
Missoula, MT 59812

Dr. Robert Lee
College of Forest Resources
123 Anderson AR-10
Seattle, WA 98195

Logan Lee
USDA Forest Service
201 E 9th Street, Suite 201
Anchorage, AK 99501

George Leighton
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Madonna Lengerich
Boise Interagency Fire Center
3905 Vista Avenue
Boise, ID 83705

Steve Lent
Bureua of Land Management
P.O. Box 550
Prineville, OR 97754

Bea Lepine
Dept. of Renewable Resources
P.O. box 1366
Hay River, NWT XOE ORO

Susan L. LeVan
USDA Forest Products laboratory
One Gifford Pinchot Drive
Madison, WI 53705-2398

Rich Levengood
Summit County
P.O. Box 816
Breckenridge, CO 80424

Keith Lewis
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

David Liebersbach
USDI, Bureau of Land Mangement
Box 35005
Ft. Wainwright, AK 99703

Mike Long
Florida

Don Lotvedt
Bureau of Land Management
2850 Youngfield Street
Lakewood, CO 80215

Loren Lucore
Fremont NF, Lakeview RD
524 North G Street
Lakeview, OR 97630

Tom Lugtenaar
Trooper Tom's Fire Protection Co.
P.O. Box 44
Manzanita, OR 97130

David M. Lukens
U. S. Forest Service
P.O. Box M
Enterprise, OR 97828

Duane Lumpry
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Ray Lundby
Montana Department of State Lands
Box 1794
Miles City, MT 59301

Charles Lundfelt
North Star Vol Fire Department
2358 Bradway Road
North Pole, AK 99705

Seth Mackie
WA State Department of Natural Res
P.O. Box 280
Castle Rock, WA 98611

Dennis Mahussier
Government of Northwest Territories
Box 7
Fort Smith, NWT, Canada XOE OPO

Frenchie Malotte
Alaska Dept. Natural Resources
P.O. Box 107005
Anchorage, AK 99510-7005

John Marker
USDAFS
P.O. Box 2417
Washington, DC 20013

Wayne Martin
Department of Forest Res & Lands
P.O. Box 2006, Herald Building
Corner Brook, NFLD CANADA AZH 6J8

Tony Martin
Florence Fire Department
Box 24
Florence, MT 59833

Peter Martin
Mt. Hood National Forest
Route 1, Box 222
Maupin, OR 97037

Lynne Mason
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Alan Masters
Environment Canada--Parks
520-220-4 Avenue, SE
Calgary, Alberta T2P 3H8

Sandy Matheny
Idaho Panhandle National Forests
1201 Ironwood Drive
Coeur d'Alene, ID 83814

Ed Mathews
Montana Dept. State Lands
2705 Spurgin Road
Missoula, MT 59801

Paul May
Montana Department of State Lands
1401 27th Avenue
Missoula, MT 59801

Robert McAlpine
School of Forestry
Missoula, MT 59812

Tim McCammon
California Department of Forestry
Route 2, Box 7
Burney, CA 96013

Glenn McDonald
Wallowa-Whitman National Forest
P.O. Box 907
Baker, OR 97814

Dave McDowell
Alaska Division of Emergency Serv
3501 E. Bogard Road
Wasilla, AK 99687

Joe McNally
USDA Forest Service, Big Valley RD
P.O. Box 159
Adin, CA 96006

Karl W. McNortor
Kansas Fire Marshal Department
900 S.W. Jackson Street, Suite 901
Topeka, KS 66612-1220

Ronald R. McOwen
Western Conservation Services
Box 851
Bozeman, MT 59715

John Means
Pattee Canyon Drive
Missoula, MT 59803

Ron Melcher
Eldon Ranger District--Coconino NF
5075 N. Hwy. 89
Flagstaff, AZ 86004

Honorable John Melcher
Montana

George F. Menner
USFS
630 Sansome Street
San Francisco, CA 94519

Robert Meuchel
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Earl Meyer
Wisconsin Dept. of Natural Res
P.O. Box 7921
Madison, WI 53707

Dennis Milburn
U.S. Forest Service--Helena NF
2001 Poplar Street
Helena, MT 59601

Melanie Miller
BLM-BIFC
3905 Vista
Boise, ID 83705

Michael T. Mitchell
National Fire Academy
16825 S. Seton Avenue
Emmitsburg, MD 21727

Dan Moerkerke
Hamilton Fire Department
Box 562
Hamilton, MT 59840

Tom Molloy
Department of Forest Res & Lands
Building T851 Pleasantville
St. John's AIC 5T7

Richard Montague
Incident Mangement Concepts
P.O. Box 31622
Walnut Creek, CA 94598

Colin Moon
Montana Department of State Lands
Clearwater State Forest
Bonner, MT 59823

Don Moore
Douglas County, Colorado
13755 W. Kentucky Drive
Lakewood, CO 80228

Penny Morgan
University of Idaho
College of Forestry
Moscow, ID 83843

Greg Morris
Montana Department of State Lands
14096 US Hwy 37
Libby, MT 59923

Daniel Mudd
Boulder County Sheriff's Dept.
P.O. Box 471
Boulder, CO 80306

John Mumma
U. S. Dept. of Agriculture
P.O. Box 7669
Missoula, MT 59807

James L. Murphy
Fire Science Systems Corporation
2220 Targee
Boise, ID 83705

Tim Murphy
Forestry Div. Montana D S L
2705 Spurgin Road
Missoula, MT 59801

William Murray
Cascade County D.E.S.
P.O. Box 3127
Great Falls, MT 59403

Rick Neff
Missoula Fire Department
446 Speedway Street
Missoula, MT 59802

Bill Neville
National Fire Academy
16825 S. Seton Avenue
Emmitsburg, MD 21727

Bruce Nicholl
Department of Forest Res & Lands
Herald Building, P.O. Box 2006
Corner Brook, NFLD CANADA A2H 6J8

Tom Nigh
Worley Fire District
P.O. Box 187
Worley, ID 83876

Jerry Nilsson
USFS, Huron-Manistee NF
421 S. Mitchel Street
Cadillac, MI 49601

Richard T. Noggles
University of Idaho

J. M. Norfleet
Payette National Forest
P.O. Box 1026
McCall, ID 83638

Judy Norgaard
USFS
Box 7669
Missoula, MT 59807

Bill O'Brien
Montana Department of State Lands
P.O. Box 490
Kalispell, MT 59901

Dennis O'Donnell
Univ. of Montana, Public Policy Inst.
2830 Larch Camp Road
Missoula, MT 59803

Anthony O'Neill
National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Kelly O'Shea
Alberta Forest Service
Bow/Crow Forest HQ, Box 3310, Station B
Calgary, Alberta T2M4L8

Chuck Oppegard
Bitterroot National Forest
316 N. Third
Hamilton, MT 59840

Sig G. Palm
USDA FS NA S&PF FP
370 Reed road
Broomall, PA 19008

William (Rett) Parker
Double Arrow Landowner's Association
P.O. Box 176
Seeley Lake, MT 59868

Ralph Parkin
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Anita Parkin
Superior Volunteer Fire Department
P.O. Box 816
Superior, MT 59872

Randy Peck
Loveland Fire Department
410 East 5th Street
Loveland, CO 80537

Pete Pederson
Salt Lake City Fire Department
159 East First Street South
Salt Lake City, UT 84111

Leo E. Perino
Newcastle, WY 82701

Bill Perrin
Montana First State Bank
300 Main Street
Stevensville, MT 59870

Jack Peters
Forestry Div. Montana DSL
2705 Spurgin Road
Missoula, MT 59801

Pete (Rowan L.) Peterson
USFS
Powers Ranger Station
Powers, OR 97466

Don Peterson
Lake County
Polson, MT 59860

R. D. Peterson
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

Howard C. Pickerd
Wyoming State Forestry Division
P.O. Box 639
New Castle, WY

David E. Poncin
U. S. Forest Service
Rt. 2, Box 475
Grangeville, ID 83530

Stephen R. Raddatz
U. S. Forest Service
5493 Warm Springs Avenue
Boise, ID 83712

Terry Randolph
USFS
1200 Franklin Street
Sparks, NV

Phil Range
BLM-BIFC
3905 Vista Avenue
Boise, ID 83705-0126

Tom Reese
USDAFS, Missoula Ranger District
5115 Highway 93 South
Missoula, MT 59801

Bruce Reid
Montana Department of State Lands
Lincoln Initial Attack Station
Lincoln, MT 59639

Jim Reinhardt
Nevada Division of Forestry
885 Eastlake Boulevard
Carson City, NV 89701

Kent Rethlake
USFS
5075 N 89
Flagstaff, AZ 86001

Carol Rice
Wildland Resource Management
134 Journey's End
Walnut Creek, CA 94595

Kenneth J. Rich
Black Eagle Vol Fire Department
811B 18th Street North
Great Falls, MT 59401-1317

Timothy Rich
U. S. Forest Service
Powell Ranger Station
Lolo, MT 59847

Roy L. Robinso
Frenchtown Vol Fire Department
Box 119
Frenchtown, MT 59839

Ron Rochna
BLM-BIFC
3905 Vista
Boise, ID 83705

Lorenzo Rodriguez
Chalender Ranger District
501 W. Bill Williams Avenue
Williams, AZ 86046

Rafael Rodriguez
USFS Bitterroot National Forest
P.O. Box 266
Darby, MT 59829

Ken Roegner
Bureau of Land Management
P.O. Box 2965
Portland, OR 97208

Tom Romaine
Minnesota Dept. of Natural Res
P.O. Box 278
Lewiston, MN 55952

Robert V. Rose
Boise, ID

Renn Ross
Boise, ID

Gordon Rowley
Forest Service, Angeles NF
701 N. Santa Anita
Arcadia, CA

Joe Rubini
East Bay Regional Parks
11500 Skyline Boulevard
Oakland, CA 94619

Marshall D. Ruegger
WI D.N.R. and Member NFES
101 S. Webster Street
Madison, WI 53707

Glendon Rummel
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

William L. Russell, Jr.
USFS
517 Gold Avenue, SW
Albuquerque, NM 87102

Merrill Saleen
USDA Forest Service
275 E. 7th Street
Weiser, ID 83672

Richard Sanders
U. S. Forest Service
324-25th Street
Ogden, UT 84401

Bob Sandman
DSL, Stillwater State Forest
P.O. Box 164
Olney, MT 59927

James Saveland
Moose Creek Ranger District
c/o Dept. of FS , Univ. of Idaho
Moscow, ID 83843

Arthur Sbarsky
Foote, Cone & Belding
11601 Wilshire Boulevard
Los Angeles, CA 90025

Rich Schell
California Dept. of Forestry
P.O. Box 944246
Sacramento, CA 94244-2460

Paul Schlobohm
BLM-BIFC
3905 Vista
Boise, ID 83705

Wyman Schmidt
Intermountain Research Station
Bozeman, MT 59717

Bob Schneider
Inter-Canyon Fire Department
7939 S. Turkey Creek Road
Morrison, CO 80465

Walt Schopfer
BLM
P.O. Box 36800
Billings, MT 59107

Vern Schwartz
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Bernard Sease
Carson City Fire Department
111 N. Curry Street
Carson City, NV 89703

Gary Severson
Dynamic Horizons, Inc.
P.O. Box 2316
Evergreen, CO 80439-2316

Dean Seyler
Warm Springs Fire & Safety
P.O. Box C
Warm Springs, OR 97761

Lori Sharn
U.S. Today

Richard Fritz Sheridan
Department of Botany
University of Montana
Missoula, MT 59812

Michael B. Sherman
La Grande Fire Department
P.O. Box 670
La Grande, OR 97850

Dave Simms
WA State Department of Natural Res
P.O. Box 68
Enumclaw, WA 98022

Dave Sisk
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Nancy Skinner
School of Forestry
Missoula, MT 59812

Win Smith
Glen Ellen Fire District
13445 Arnold Drive
Glen Ellen, CA 95442

Frank K. Smith
New Mexico Natural Resources Dept.
P.O. Box 2167
Santa Fe, NM 87504

Brooke Smith
Aspen Engineering, Inc.
P.O. Box 4338
Woodland Park, CO 80866

Richard Smith
Lewis & Clark National Forest
P.O. Box 871
Great Falls, MT 59403

Kathy Smith
U.S Forest Service, LaGrande R.D.
3502 Highway 30
LaGrande, OR 97850

Glenn Snyder
R2 AAFM
11177 W 8th Avenue
Lakewood, CO 80225

Walt Soper
Weston County Firefighters
P.O. Box 931
Newcastle, WY 82701

Jerry Sorensen
Lake County
Courthouse
Polson, MT 59860

Dennis Spray
Union County
1109 K Avenue
LaGrande, OR 97850

Dave Stack
U. S. Forest Service
824 Parkview
Missoula, MT 59803

Chuck Stanich
Stevensville Ranger District
88 Main Street
Stevensville, MT 59870

Richard Stauber
San Bernardino National Forest
1824 Commercenter Circle
San Bernardino, CA 92408

Karen-Dorn Steele
Spokesman Review
Spokane, WA

Sonny Stiger
Montana Prescribed Fire Services, Inc.
P.O. Box 164
Wolf Creek, MT 59648

Philip Stromberg
Wisconsin Dept. Natural Resources
Ranger Station Box 51
Webster, WI 54893

Bruce Suenram
Missoula Rural Fire District
2521 South Avenue West
Missoula, MT 59801

Martin L. Suhr
U. S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, NM 87103

Paul Summerfelt
Colorado State Forest Service
7980 Highway 50 W
Salida, CO 81201

Mike Supkis
Lewiston Rural Fire Service
2795 Grelle Avenue
Lewiston, ID 83501

R. C. "Slim" Tallada
Creston Volunteer Fire Department
5060 MT35
Kalispell MT 59901

Ed Tennant
Hamilton Fire Department
Box 562
Hamilton, MT 59840

Ross Tervo
Powell County
409 Missouri Avenue
Deer Lodge, MT 59722

Bill Thomas
MT Disaster & Emergency Services
2501 Reserve Street
Missoula, MT 59801

Donald Thompson
East Grand Fire District No. 4
P.O. Box 360
Winter Park, CO 80482

Brooke Thompson
USDA Forest Service
88 Main Street
Stevensville, MT 59870

Nancy Thormahlen
Lake County Land Services
Lake County Courthouse
Polson, MT 59860

Howard Thronson
WA State Department of Natural Res
4224 6th Avenue SE, Building 1
Lacey, WA 98503

Gary Tokle
National Fire Protection Assoc
1 Batterymarch Park
Quincy, MA 02269

Ginny Tribe
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Betty Tucker
Clinton Rural Fire District
Box 237
Clinton, MT 59825

Dan Turner
CDF/County Fire
6059 Highway 9
Felton, CA 95018

Harold A. Turner
Salt Lake City Fire Department
159 E. 1st South
Salt Lake City, UT 84111

Cordy Tymstra
Yoho National Park
Field, British Columbia
Canada VOA IGO

Terry Vaughn
Montana Department of State Lands
7916 Highway 10A West
Anaconda, MT 59711

Maurice Vogel
Community Colleges of Spokane
S. 825 Center Drive
Spokane, WA 99212

Richard Vollick
USDA Forest Service
88 Main Street
Stevensville, MT 59870

Joe Wagenfehr
USDA Forest Service, Region 1
P.O. Box 7669
Missoula, MT 59807

Ron Wakimoto
University of Montana
Department of Forestry
Missoula, MT 59812

William A. Walkup
Spokane County Fire District No. 8
East 12100 Palouse Highway
Valleyford, WA 99036

Steve Wallace
Montana Department of State Lands
Clearwater State Forest
Bonner, MT 59823

Roger Wallace
Forest Service
600 Sherbourne
Leavenworth, WA 98826

Bill Wallis
700 West State Street
Boise, ID 83720

Michael Warner
Loveland Fire Department
410 E. 5th Street
Loveland, CO 80537

Craig D. Warren
SD Dept. of Agriculture
3305-1/2 West South Street
Rapid City, SD 57702

William Waterbury
Wallowa-Whitman National Forest
P.O. Box 907
Baker, OR 97814

John Waverek
Missoula Ranger District
Building 24-A, Fort Missoula
Missoula, MT 59801

Robert Webber
BLM-BIFC
3905 Vista
Boise, ID 83705

Seldon Weedon
MT Fire Services Training School
2100 16th Avenue South
Great Falls, MT 59405-4997

Jerry Weigard
USFS
606 Dawn Drive
Grangeville, ID 83530

Meredith A. Weltmer
U. S. Fish and Wildlife Service
Wichita Mts. Wildlife Refuge
Indiahoma, OK 73552

Rick West
Chelan County Fire District No. 1
P.O. Box 2106
Wenatchee, WA 98801

Allan J. West
U. S. Forest Service
8870 Applecross Lane
Springfield, VA 22153

Hal H. Wetzsteon
Beaverhead National Forest
160 N. Montana
Dillon, MT 59725

Laurence J. Whelan
Coconino National Forest
2323 E. Greenlaw Lane
Flagstaff, AZ 86004

Bill Wilburn
WA State Department of Natural Res
225 South Silke Road
Colville, WA 99114

Larry L. Wiles
Nebraska Forest Service
105 Plant Industry Bldg., UN-L
Lincoln, NE 68583-0814

Don Willis
BLM-BIFC
3905 Vista Avenue
Boise, ID 83705

Fritz Wilson
Missoula City Fire Department
200 W. Pine Street
Missoula, MT 59802

Dale Wilson
U. S. Forest Service, Rogue River NF
P.O. Box 520
Medford, OR

Dan Winner
USFS
517 Gold Avenue, SN
Albuquerque, NM 87102

Rory Wold
Idaho Panhandle National Forests
1201 Ironwood Drive
Coeur d'Alene, ID 83814

Richard Wolfe
Pocatello Fire Department
408 E. Whitman
Pocatello, ID 83201

Don Wood
Wood Forestry Services
2610 Meridian Road
Victor, MT 59875

Gavriil Xanthopoulos
University of Montana
School of Forestry, SC 460
Missoula, MT 59812

William Yount
Lolo National Forest
Building 24, Fort Missoula
Missoula, MT 59801

Ronald J. Zeleny
Colorado State Forest Service
203 Forestry, C.S.U.
Fort Collins, CO 80523

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**Intermountain
Research Station**

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The Douglas-fir/ Ninebark Habitat Type in Central Idaho: Succession and Management

Robert Steele
Kathleen Geier-Hayes

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THE AUTHORS

ROBERT STEELE is a research forester assigned to the Rocky Mountain Douglas-fir and Ponderosa Pine Ecosystems research work unit at Boise, ID. Since joining the Intermountain Station in 1972, he has concentrated on development of forest habitat type classification, and on classification and management of successional forest communities. He earned a B.S. degree in forest management and an M.S. degree in forest ecology at the University of Idaho.

KATHLEEN GEIER-HAYES is a forester in the Rocky Mountain Douglas-fir and Ponderosa Pine Ecosystems research work unit. She has worked part time on the classification and management of successional forest communities since the beginning of this project in 1979 and joined the Intermountain Station on a full-time basis in 1986. She earned a B.S. degree in biology at Boise State University and an M.S. degree in forest science at the University of Idaho.

ACKNOWLEDGMENTS

Financial support for this study was provided by the Intermountain Region of the Forest Service, U.S. Department of Agriculture, through a memorandum of understanding with the Intermountain Research Station.

Staff of the Boise, Payette, and Salmon National Forests assisted at various times with logistical support and helpful information during field sampling. Phil Straub (Boise National Forest), Glenn Jacobsen (Payette National Forest), and Doug Basford (Salmon National Forest) provided support and advice on the development of this study. Pete Stickney and Steve Arno (Intermountain Research Station) generously shared their data and insight on similar forest succession studies.

RESEARCH SUMMARY

A succession classification system for the Douglas-fir/ninebark habitat type is presented. It is based on reconnaissance sampling of 152 stands: 27 old-growth sites, 31 pairs of old-growth versus disturbance sites, and 63 additional disturbed sites. A total of six potential tree layer types, 28 shrub layer types, and 55 herbaceous layer types are categorized by a hierarchical taxonomic classification. Diagnostic keys based on indicator species are provided for field identification of the layer types.

Implications for natural resource management are provided based on field data and observations. These implications include: occurrence of pocket gophers and success of tree plantations by site preparation treatments, initial growth rates of tree seedlings and yield capability of mature trees, microsite needs of natural tree seedlings, big-game and livestock forage preferences of shrub and herb layer types, and responses of major shrub and herb layer species to various disturbances. Species composition data for each of the tree, shrub, and herb layer types that were sampled are displayed in tables.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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The Douglas-fir/Ninebark Habitat Type in Central Idaho: Succession and Management

Robert Steele
Kathleen Geier-Hayes

INTRODUCTION

Over much of the Western United States, development of habitat type classifications based on potential natural vegetation (Pfister 1984) has increased professional awareness of vegetation and its variability. Those who manage natural resources now recognize the need to foresee the changes in vegetation that may result from management activities. But to understand and communicate these changes, one's perspective must encompass the often bewildering integration of cause and effect, and random, cyclic, and temporal relationships that are manifest in succession dynamics. Logically, the first step is to classify seral vegetation into a manageable number of recognizable units.

Habitat type classifications focus on the environmental (site) differences affecting vegetation. They provide a logical framework for studying succession and occasionally infer successional relationships but offer no classification of seral communities. As one approach to meeting this need, we present herein a classification of seral vegetation designed for general field use. In so doing, we have attempted to exploit the fact that natural classifications, in contrast to technical ones designed for a specific use, have broader application and often provide greater prediction capability. The widely accepted habitat type system of classification is an outstanding example of a natural classification, and as its originators, R. and J. Daubenmire (1968), have pointed out "... that system may be considered the closest to a natural one that allows the most predictions about a unit from a mere knowledge of its position in the system." We developed the following classification with these criteria in mind so that the relative position of a classified unit in the system can help predict the successional direction of that unit. In doing this, we found that some types of seral vegetation are strongly related to a specific disturbance; other types develop mainly through uninterrupted succession. These cause and effect relationships are presented in various ways in the sections dealing with classification as well as those dealing with management implications.

Throughout this text the reader must remember that vegetation is influenced by two independent variables: time and environment. Environment, as it affects vegetation, can be delineated by habitat types or potential climax communities (Daubenmire 1952) that are relatively stable barring disturbance. In a similar manner, time, as it relates to succession, can be delineated by community types or seral stages that can be obliterated, slightly altered, or even advanced through various disturbances. Habitat type classifications have proven useful in much of the West (Layser 1974) and by focusing on climax potential enable investigators to hold time constant while grouping plant communities that have similar environments. Conversely, environment can be held relatively constant by using habitat types while focusing on seral vegetation.

This report presents the seral vegetation and related resource values occurring over time in one forest environment, the *Pseudotsuga menziesii / Physocarpus malvaceus* habitat type (PSME/PHMA h.t.) (Steele and others 1981). The classification approach used here accommodates the individual nature of specific sites in terms of existing and potential species composition. It also accommodates the land manager's need for site-specific guidelines for intensive management purposes. In this regard, management implications for many species can be derived from each species' reaction to a particular disturbance and its successional strategy. This report can be applied to specific sites by understanding the successional characteristics presented for each major species and then synthesizing that knowledge for the existing and potential species on a particular site. Sometimes, the preliminary nature and meager data base herein require tentative use as a management guide. Throughout this report, users should focus on the relative nature of data presented rather than absolute values. Because this report was developed through a series of approximations, it should always be open to further refinement. We welcome suggestions and comments.

This report uses a classification system (Steele 1984) that recognizes the somewhat independent nature of succession between the tree, shrub, and herbaceous layers (often due to layer-specific disturbances such as selective tree harvesting or grazing) and treats these three successions separately. It recognizes the high potential diversity of early and mid-seral vegetation and the relative forage values to livestock and big game. It also indicates some interrelationships of site treatment, planted and natural tree survival, competing vegetation, and pocket gopher populations. Most important, it provides a common framework for communication among various resource disciplines.

Objectives

The objectives of this report are:

1. To develop a classification of seral vegetation in the PSME/PHMA h.t. based on indicator species and vegetal structure.
2. To identify successional relationships of seral vegetation and the kinds of disturbances that generate this vegetation.
3. To present species composition and canopy coverage information for each shrub and herbaceous layer and the relative value of these layers as forage for big game and livestock.
4. To describe suitable conditions for natural and artificial establishment of tree seedlings and early growth characteristics of trees in relation to site treatment, microsite conditions, and competing vegetation.
5. To determine the number of years required for each tree species to reach breast height (4.5 feet, 1.4 m) in the PSME/PHMA h.t.
6. To provide a basis for developing preliminary management implications by seral community type.

Methods

This report is the second of a series on succession and management in forest habitat types. The methods used herein are identical to those of the previous report covering the grand-fir/blue huckleberry habitat type (Steele and Geier-Hayes 1987b). In general, sampling methods were similar to those used in the central Idaho habitat type study (Steele and others 1981). Circular plots (375 m^2 in size) were subjectively located so as to represent the range of site conditions and vegetal diversity characteristic of the habitat type. Recorded observations included age of last disturbance; plant coverage by species; percentage survival and age to 4.5 feet (1.4 m) of planted tree seedlings; occurrence of pocket gopher mounds and snow damage to tree seedlings; methods of logging, slash disposal, and site preparation; and thickness of duff layer. The plant coverage data (see appendix) were used to develop a succession classification (Steele 1984) and were later assembled in synthesis tables (Mueller-Dombois and Ellenberg 1974) to verify the early seral to climax arrangement of stands as indicated by the classification.

THE PSME/PHMA HABITAT TYPE

Distribution

In the *Pseudotsuga* series of the Northern Rockies, PSME/PHMA is second only to the Douglas-fir/pinegrass habitat type in extent of geographic distribution. PSME/PHMA ranges from northeastern Washington, northern Idaho, and adjacent British Columbia (Daubenmire and Daubenmire 1968) to northeastern Oregon (Hall 1973; Johnson and Simon 1987), central Idaho (Steele and others 1981), and western Montana (Pfister and others 1977). It also occurs in southeastern Idaho and western Wyoming (Steele and others 1983) and northern and central Utah (Mauk and Henderson 1984; Youngblood and Mauk 1985). The *Pseudotsuga / Physocarpus monogynous* h.t. in north-central Wyoming (Hoffman and Alexander 1976) and north-central Colorado (Hess 1981) is similar in appearance but less productive.

This broad geographic distribution is accompanied by considerable diversity, part of which is characterized by phase designations (table 1). The occurrence of tree species by phase is shown in table 2. In northern Idaho, PSME/PHMA consists of two phases, a moist phase that can support *Larix* and has *Smilacina stellata* and *Disporum hookeri* as climax indicators (SMST phase) and a drier condition (PHMA phase) that does not support *Larix* or *S. stellata* and *D. hookeri*. These two phases have also been recognized in Montana (table 1). The drier PHMA phase is quite similar to the PIPO phase of central Idaho but should be distinguished from the original PHMA phase described in Montana (table 1).

In central Idaho, PSME/PHMA ranges in elevation from about 3,100 to 7,100 feet (945 to 2,164 m). It occurs on virtually every aspect but is most common on northerly (270° to 90° azimuth) slopes and least common on south to southwesterly slopes. In fact, only two out of 152 sample plots in central Idaho occurred on slopes having an azimuth between 180° and 225°. PSME/PHMA represents a relatively warm, moist environment and usually indicates a site with ample cold air drainage; rarely, if ever, does it occur in frost pockets. PSME/PHMA occurs on a variety of substrates that include basaltic, granitic, and sedimentary parent materials. It is most common in the Boise and Payette River drainages, but can be found in varying abundance in most major river drainages of central Idaho (fig. 1). Most PSME/PHMA in the Boise and Payette drainages occurs within the range of *Pinus ponderosa* and is designated the PIPO phase. Because this phase receives much more silvicultural activity than the other phases, it is the primary phase addressed in this report.

Eastward through central Idaho, PSME/PHMA extends into more severe environments where *Pinus ponderosa* is absent. These sites have been designated the PSME phase and are found in the more continental climate of east-central Idaho where they occur as high as 7,100 feet (2,164 m). The PSME phase also occurs sporadically along the juncture of the Snake River Plains and the Idaho batholith (fig. 1), where it occurs as low as 3,500 feet (1,067 m). In these areas the PSME phase is a topographic climax of north-slope canyon lands, which are generally associated with the Snake River Plain (where the climatic climax is nonforest). This contrasts with the adjacent mountains (where the climatic climax is forest) that support the PIPO phase. Apparently the adjacent mountain mass prolongs the benefits of passing storms through greater cloud cover and more moderate temperatures. Soil differences may also exacerbate these subtle climatic differences, which is often the case along the periphery of a plant species or habitat type distribution where conditions become most stressful. Total precipitation may be greater in the PIPO phase, but this is not likely a differentiating factor since the pine can occupy drier sites than *Pseudotsuga* or *Physocarpus* in areas where other factors are more favorable. Because of relatively little management activity in the PSME phase only sparse data are available for successional study.

Table 1—Phase designations of the PSME/PHMA h.t. suggested by various studies

Study	None	PHMA	PHMA -moist (SMST)[1]	PHMA -dry (PHMA)	CARU	PIPO[2]	PSME	PAMY
Northern Idaho								
R. and J. Daubenmire (1968)	X[3]	.	O	O	.	.	.	.
Daubenmire (1973)	.	.	X	X	.	.	.	.
Cholewa (1977)	X	.	O	O	.	.	.	.
Cooper and others (1987)	.	.	X	X	.	.	.	.
Western Montana								
Pfister and others (1977)	.	X	O	O	X	.	.	.
Arno and others (1985)	.	.	X	X	.	.	.	.
Eastern Oregon								
Hall (1973)	X	.	X	X	.	.	.	.
Johnson and Simon (1987)	X[4]	.	.	O	.	.	.	.
Central Idaho								
Steele and others (1981)	.	.	.	.	X	X	X	.
Eastern Idaho-western Wyoming								
Steele and others (1983)	.	.	.	.	.	.	X	X
Utah								
Mauk and Henderson (1984)	X	.	.	.	.	.	.	O
Youngblood and Mauk (1985)	X	.	.	.	.	.	.	O

[1] The moist and dry variants of the original PHMA phase in Montana (Pfister and others 1977) have been named the *Smilacina stellata* and *Physocarpus malvaceus* phases, respectively, in northern Idaho by Cooper and others (1987).

[2] The PIPO phase in central Idaho is similar to PHMA (dry).

[3] X = phase defined; O = phase suggested by data or text.

[4] These studies also describe a PSME/ACGL-PHMA association that closely resembles a moist extreme of the PIPO phase but is not transitional to the SMST phase.

Table 2—Occurrence of tree species in phases of the PSME/PHMA h.t.[1]

		Phases				
ADP No.	Tree species	SMST	PHMA (dry)	PIPO	PSME	PAMY
001	*Abies grandis*	a[2]	a	a	.	.
006	*Larix occidentalis*	S	a	.	.	.
010	*Pinus contorta*	s	(s)	.	(s)	a
011	*Pinus flexilis*	.	.	.	(s)	(s)
013	*Pinus ponderosa*	S	S	S	.	.
014	*Populus tremuloides*	.	(s)	(S)	a	(s)
015	*Pseudotsuga menziesii*	C	C	C	C	C

[1] Derived from Cooper and others (1987), Arno and others (1985), Johnson and Simon (1987), Steele and others (1981, 1983).

[2] S = major seral a = accidental occurrence
s = minor seral ( ) = occurs in only part of the phase
C = major climax.

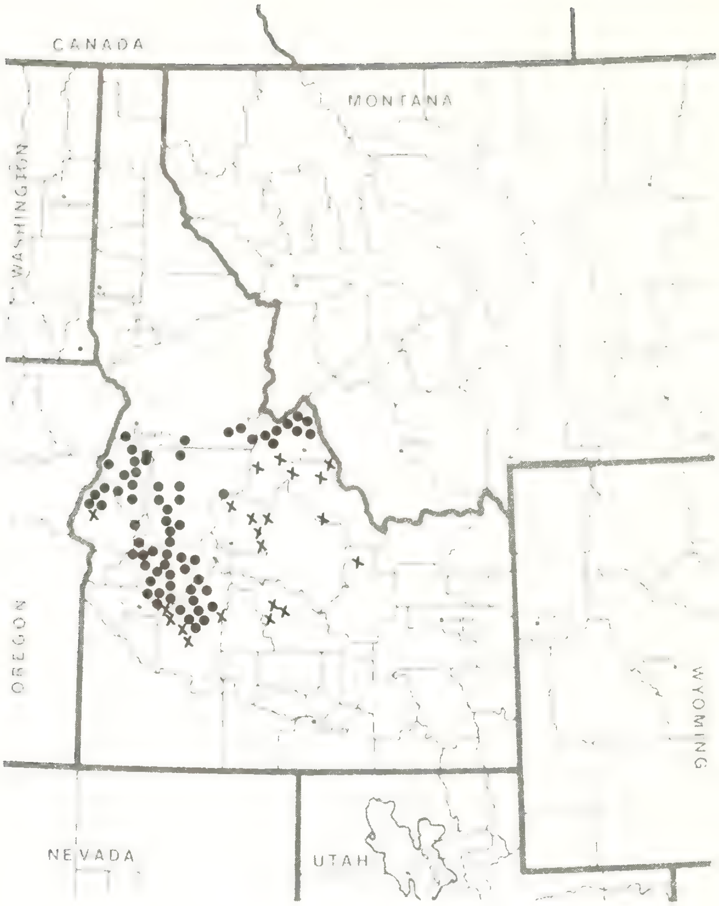

Figure 1—Distribution of the PSME/PHMA h.t. in central Idaho, PIPO phase (•) and PSME phase (x).

The CARU phase is reported for central Idaho and Montana (table 1) but is uncommon in Idaho. We intended to use this phase to delineate a broad transition between the PSME/PHMA and *Pseudotsuga menziesii / Calamagrostis rubescens* (PSME/CARU) habitat types. Unfortunately, the idea has limited value because some seral stages of the PIPO, or PHMA dry, phase can be easily misidentified as the CARU phase since these phases all support the same species. Although the CARU phase may exist in some areas its taxonomic use has been discouraged and its successional features have not been studied in Idaho or Montana (Arno and others 1985).

The PAMY phase (table 1) occurs mainly in southeastern Idaho, adjacent Wyoming, and northern Utah. Its southernmost occurrence lies in the northern Fish Lake Plateau of central Utah (Youngblood and Mauk 1985). This phase is a rather isolated geographic variant of PSME/PHMA. *Pinus ponderosa* is entirely absent but *Populus tremuloides* and occasionally *Pinus contorta* are common. Successional characteristics of this phase have not been studied.

Description (PIPO Phase Only)

In central Idaho, the PIPO phase occurs between 3,100 and 6,400 feet (945 and 1,951 m) in elevation and indicates relatively warm, moist sites with good cold air drainage. At its moist extremes, this phase can support most species found in adjacent *Abies grandis* habitat types except the *Abies*. Eastward, beyond the range of *Abies grandis*, the PIPO phase may adjoin the Douglas-fir/mountain maple habitat type where cooler temperatures exclude *Physocarpus*. The dry limits of this phase are determined by the drought tolerance of *Physocarpus*. Wherever this shrub is unable to develop a canopy, the Douglas-fir/white spirea, Douglas-fir/pinegrass, or Douglas-fir/elk sedge habitat type will prevail, depending on slight differences in soil and topography. Seral communities within the PIPO phase can vary as a result of their proximity to these other habitat types.

EARLY SERAL

Early seral communities tend to reflect the greatest species diversity for a given habitat type. In PSME/PHMA, *Populus tremuloides* may dominate the tree layer, particularly on old landslides. But usually there is no early seral tree layer, and a dense shrub layer dominates the site. *Ceanothus velutinus* is usually a prevalent member of early seral stages, but in areas to the north and east of Banks, ID, *C. sanguineus* is the most common ceanothus. High coverages of either species usually reflect past burning; lesser amounts can result from scarification. High coverages of *Ribes cereum* or *R. viscosissimum* also reflect early seral stages and are usually the result of scarification without burning. *Ribes viscosissimum* occurs mainly at the moist extremes of the PIPO phase, while *R. cereum* can occur throughout the phase. *Ribes*-dominated communities are relatively rare, however, possibly due to the difficulty of achieving thorough scarification on these steep sites.

Numerous herbaceous species can appear in the early seral stages. Annual species of *Gayophytum, Epilobium, Cryptantha, Polygonum, Clarkia, Bromus,* and occasionally other genera denote the earliest stages of herb layer succession. *Potentilla glandulosa, Rudbeckia occidentalis,* and sometimes *Agastache urticifolia* indicate heavily grazed conditions. Occasionally, *Iliamna rivularis* is prevalent where there has been severe burning such as from slash piles. *Bromus carinatus* and *Geranium* have high coverages where there has been little grazing or recovery from heavy grazing. These conditions often appear as a perplexing mosaic that is best interpreted through repeated observations of larger, more uniform areas where the vegetation has reacted to a single disturbance.

MID-SERAL

Mid-seral tree layers support a mixture of *Pinus ponderosa* and *Pseudotsuga,* proportions of which often reflect the nature and frequency of past wildfires or logging. As the tree canopy increases, the shrub layer also undergoes change. The shade-intolerant shrubs *Ceanothus* and *Ribes* decline, leaving the more tolerant *Salix* and *Prunus* as indicators of mid-seral stages. *Salix scouleriana* is often a prominent shrub at this stage. It establishes from seed or resprouts from stumps in early seral stages and develops a rounded shape in the full sun. But as the overstory shade increases, the *Salix* outline changes to a narrow upright growth form beneath openings in the tree canopy. *Prunus emarginata* and, less often, *P. virginiana* are also prevalent in some areas. These *Prunus* communities often appear somewhat stable, and many have a history of repeated wildfire. *Salix* and *Prunus* also exhibit subtle differences in site requirements. The *Prunus* species are more common on upper slopes and ridges (probably warmer) whereas *Salix* is more prevalent at mid-to-lower slope and in concave terrain (more moisture). These different site requirements become more apparent in progressively drier, more severe habitat types where both genera are seldom well represented on the same site. In the herbaceous layer, the early seral species decline substantially beneath the increased shade. More tolerant species such as *Penstemon attenuatus, Epilobium angustifolium,* and *Fragaria* may remain well represented. Climax taxa such as *Arnica, Calamagrostis,* and *Thalictrum* may already be dominating these mid-seral associates.

CLIMAX

In near-climax to climax stages, Douglas-fir is the dominant tree and often forms pure stands. But low coverages of ponderosa pine may persist due to that tree's greater height and long life span. Shrub layers become increasingly simple and consist mainly of *Physocarpus, Symphoricarpos oreophilus, Amelanchier,* and *Spiraea.* The herbaceous layer has also decreased in species diversity and consists mainly of shade-tolerant rhizomatous species. *Aster conspicuus, Carex geyeri, Arnica, Calamagrostis,* and *Thalictrum* are the primary components of near-climax conditions.

SUCCESSIONAL FEATURES

Succession Classification

A systematic classification of seral vegetation within the PSME/PHMA h.t. was developed as part of this study. The basic approach (Steele 1984) uses indicator species according to their ability to dominate a seral stage and their relative successional amplitude (relative vulnerability to successional replacement). The relative amplitudes can be arranged along the successional gradient and are inversely related to indicator value. Figure 2 shows an example of this arrangement for the major tree species in PSME/PHMA. These indicators are then combined with possible dominant tree species to provide a temporal-structural framework for classifying seral tree layers. Figure 3 shows the classification framework derived from figure 2. Shade tolerance is often assumed to be the factor that determines successional amplitude, but, as Minore (1979) suggests, other competitive factors may be involved. Bazzaz (1979) addresses numerous physiological factors that affect a plant's ability to compete with its associates. Species longevity, light quality and nutrient requirements, allelopathic and disease resistance, and reproductive strategy are some of the factors involved. Fortunately, the integrated effects of all competitive factors, whether known or unknown, can be interpreted through relative successional amplitudes, which in turn provide a successional time scale for classification purposes. Using indicator species to delineate seral stages may be less than ideal for some applications but provides an ecologically based classification suitable for most resource management activities. In contrast, if time is used on a yearly scale to classify seral communities, the relationship becomes untenable due to the randomness of successional forces such as seed crops, insects, disease, weather, and combinations thereof.

The Tree Layer

Because tree, shrub, and herb layer succession occurs at different rates and may be affected by layer-specific disturbances, this classification focuses on the individual layers. The tree layer (trees more than 4.5 feet [1.4 m] tall) in PSME/PHMA is easy to classify because it contains only three major species. Relative successional amplitudes of these species are shown in figure 2. *Populus tremuloides* is clearly less tolerant than the associated conifers. *Pinus ponderosa* is less shade tolerant than *Pseudotsuga* (Minore 1979), and the pine seedlings will not survive beneath the denser canopy of *Pseudotsuga.* Once the older pines in the stand have declined and become poorly represented, another successional segment is delineated. The passing of each major seral species marks a segment in the successional sequence.

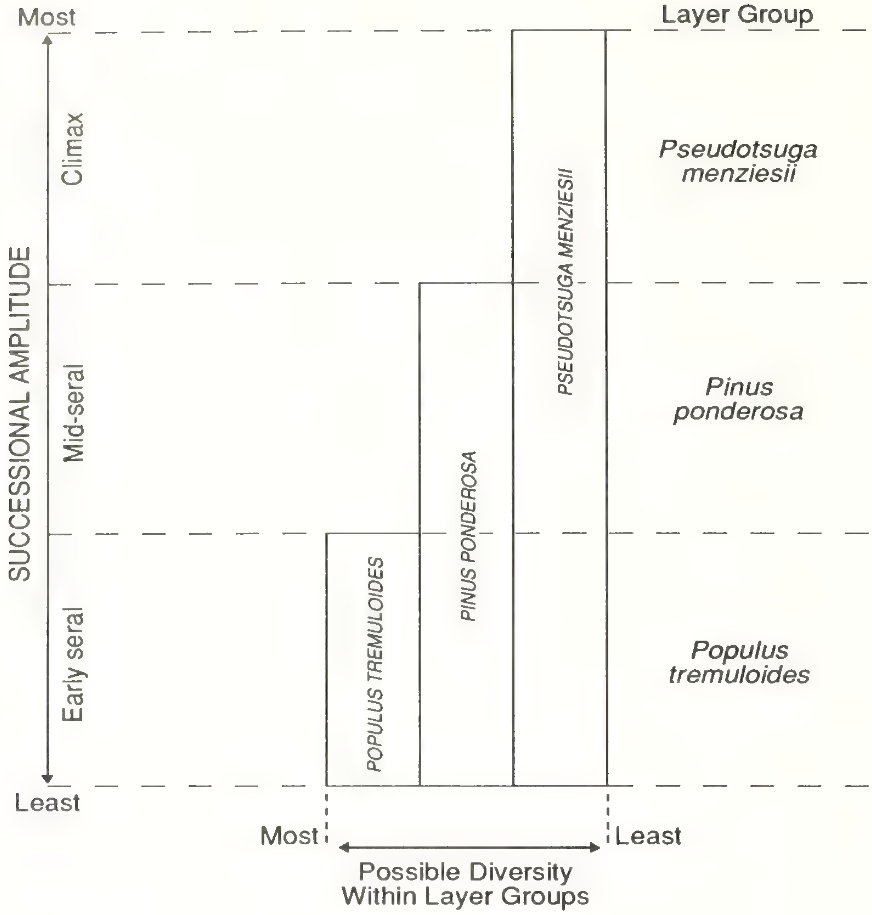

Figure 2—Relative successional amplitudes of major tree species in the PSME/PHMA h.t., PIPO phase.

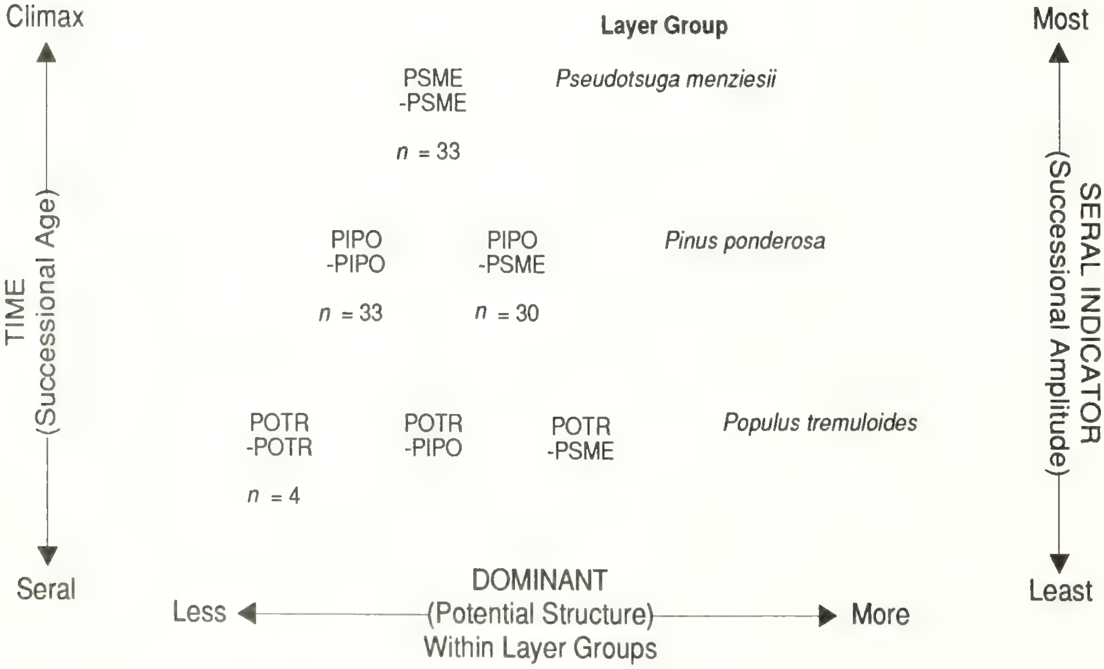

Figure 3—Succession classification diagram of the tree layer in the PSME/PHMA h.t., PIPO phase (*n* = number of samples in each layer type).

Pseudotsuga, being the most shade tolerant, has the greatest successional amplitude and acts as the climax tree. Although various factors often preclude the entire replacement sequence, the relative successional amplitudes have been established for classification purposes.

Figure 2 suggests that possible species diversity of the tree layer is greatest in the early seral stages. Here all three species could be well represented, although usually this is not the case. In the climax stage, however, only *Pseudotsuga* will be well represented, with all other tree species poorly represented or absent. A diminishing species diversity during secondary succession becomes more apparent in the shrub and herb layer classifications where more species occur.

Figure 3 shows the possible seral conditions in the tree layer that may converge to a common climax layer of *Pseudotsuga. Populus tremuloides* forms the base of the triangle because it has the least successional amplitude. Other species are arranged in ascending order as a reflection of their progressively greater successional amplitudes. Each taxonomic unit in figure 3 consists of a seral indicator species followed by the dominant species. In order to maintain a systematic structure, each taxonomic unit in figure 3 is called a layer type, and each group of layer types having the same seral indicator is called a layer group. Layer groups denote the various seral stages that are possible within a given habitat type or phase. Layer types within one layer group such as PIPO-PIPO and PIPO-PSME in the PIPO layer group denote the structural conditions that are possible in that particular seral stage. Similar classifications were developed for the shrub and herb layers. If desired, taxonomy of the tree, shrub, and herb layers can be combined to characterize the entire plant community.

In the PSME phase, only *Pseudotsuga* is well represented, so only a PSME-PSME tree layer type can result. This phase has an environment less favorable for other tree species than the PIPO phase so fewer species are well represented and consequently fewer tree layer types exist. The phase also occupies less area than the PIPO phase and experiences considerably less management activity. Consequently, there are insufficient data to develop specific management implications for this phase.

Delineating the vertical axis (successional time) into layer groups (fig. 3) provides an ecological basis for segmenting the succession. As succession progresses, a stand's classification status will progress from one layer group to a successionally older layer group. For instance, *Pinus ponderosa* (well represented) may dominate the tree layer (PIPO-PIPO) or may be dominated by *Pseudotsuga* (PIPO-PSME). But the presence of *Pinus ponderosa* can always be interpreted as a specific segment of the succession because the potential to be outcompeted by *Pseudotsuga* always exists. *Pinus ponderosa* is unable to replace *Pseudotsuga* without the aid of disturbance but can always outcompete *Populus tremuloides.*

Figure 3 serves as a **classification diagram** (not a succession model) for seral tree layers in the PSME/PHMA h.t. These and the other diagrams herein do not outline actual successions for a given site, but rather illustrate the possibilities within the habitat type. Actual successions skip many layer types and even layer groups within their respective diagrams. A succession can be described in terms of the layer types shown (fig. 3), but is determined by species composition of the stand and available seed sources.

Figure 3 also serves as a basis for constructing a simple key to tree layer types for field use. This is done by starting with the earliest layer group in figure 3 and progressing along the time gradient to climax (table 3). Keys to the shrub and herb layer types are constructed the same way. These keys are intended to be used in the same manner as the habitat type keys (Pfister and others 1977; Steele and others 1981).

SIZE CLASS NOTATIONS

The basic classification approach used in the tree, shrub, and herb layers was presented in figures 2 and 3 and table 3, but the tree layer progresses through recognizable size classes of development such as sapling (0.1-4 inches [0.25-10.2 cm] d.b.h.), pole (4-12 inches [10.2-30.5 cm]), mature (12-18 inches [30.5-45.7 cm]), and old-growth (>18 inches [45.7 cm]). These notations should be added so as to delineate stand structure even though they do not necessarily denote stand age. These notations are best added to each tree species after the tree layer type (l.t.) is identified, such as: mature PIPO-sapling PSME l.t. For consistency, the smallest size class that is well represented should be noted for the seral indicator because it usually reflects the most recent regeneration of that particular species. For the dominant species, the dominant size class should be used. When the seral indicator or the dominant species is well represented in the stand but not in any one size class, the size class with the most coverage should be noted. For convenience, size class notations can be abbreviated as follows: s. – sapling; p. – pole; m. – mature; and o.g. – old-growth.

It may be difficult, at first, to visualize some tree layer types in their appropriate successional position. For instance, a s. PSME – s. PSME l.t. may not seem to be successionally older than an m. POTR – p. PSME l.t., because we normally think of time-related situations on a yearly (or age) scale. On a successional scale, however, a pure stand of sapling *Pseudotsuga* is closer to climax than a mixed older stand of *Populus* and *Pseudotsuga* because it will not go through the earlier seral stages of the POTR and PIPO layer groups. In fact, an s. PSME – s. PSME l.t. may even reach climax in fewer years because no species replacement (succession) is needed whereas an m. POTR – p. PSME l.t. must first lose the *Populus* and if *Pinus ponderosa* is well represented must also pass through a PIPO-PSME l.t. before reaching climax.

The three possible tree layer groups in PSME/PHMA (fig. 3) are described below and delineate tree layer succession into relatively broad segments. Because layer group delineations are usually based on a single indicator species, their origin can be related to a somewhat consistent set of site conditions. But progression from one layer group to another (and one layer type to another) depends on composition of the individual stand and is therefore predictable only from field observation. The following layer group descriptions are presented in the order they

Table 3—Key to tree layer group and layer types, with ADP codes, in the PSME/PHMA h.t.

		ADP codes
1. *Populus tremuloides* well represented (≥5%)[1] (Choose first condition that fits)	POTR Layer Group	014
1a. *Populus tremuloides* dominant	POTR-POTR Layer Type	014.014
1b. *Pinus ponderosa* dominant or codominant	POTR-PIPO Layer Type	014.013
1c. *Pseudotsuga menziesii* dominant or codominant	POTR-PSME Layer Type	014.016
1. *P. tremuloides* poorly represented (<5%)	2	
2. *Pinus ponderosa* well represented (≥5%) (Choose first condition that fits)	PIPO Layer Group	013
2a. *Pinus ponderosa* dominant	PIPO-PIPO Layer Type	013.013
2b. *Pseudotsuga menziesii* dominant or codominant	PIPO-PSME Layer Type	013.016
2. *P. ponderosa* poorly represented (<5%)	3	
3. *Pseudotsuga menziesii* well represented (≥5%)	PSME Layer Group	016
3a. *Pseudotsuga menziesii* dominant	PSME-PSME Layer Type	016.016
3. *P. menziesii* poorly represented (<5%)	depauperate or undescribed tree layer or not PSME/PHMA h.t.	

[1] "Well represented" means canopy cover ≥5 percent regardless of diameter classes of the trees involved. Trees less than 4.5 feet (1.4 m) tall should be omitted from coverage estimates. "Dominant" refers to greatest canopy cover, "codominant" refers to nearly equal canopy cover. When keying to layer type, choose first condition that fits.

appear in the key (table 3). Constancy and average cover of species within sampled layer types appear in appendix A.

POPULUS TREMULOIDES LAYER GROUP (POTR L.G.)

Populus tremuloides can establish by seed on newly exposed mineral soil that remains moist during the critical germination period. Viability of freshly fallen seed usually exceeds 90 percent but lasts only about 3 weeks (Brinkman and Roe 1975). Occasional *Populus* seedlings have established in well-scarified areas, some drier than PSME/PHMA, but usually the young trees occur as root sprouts following fire or logging. If large *Populus* trees are cut or burned, their roots can produce numerous sprouts if sunlight is adequate. The sprouts provide excellent browse for deer and elk.

In the PSME/PHMA h.t., the POTR l.g. consists of three possible layer types (fig. 3). These layer types usually result from resprouting of scattered, often decadent, *Populus* following overstory removal by wildfire or logging. When *Populus* is present in the stand and no conifers establish soon after disturbance, a POTR-POTR layer type can result (fig. 4). In this layer type, subsequent invasion by conifers may be slow even when seed sources are nearby. Reasons for this are unclear, but Younger, Koch, and Kapustka (1980) have shown that leaf litter of *Populus tremuloides* can chemically inhibit seedling growth of several grasses. Possibly, conifer seedlings are also affected. Because the POTR-POTR layer type creates only light shade it can allow lush development of the shrub and herbaceous layers which also hinder conifer establishment. Simultaneous establishment of *P. ponderosa*, or *Pseudotsuga* with the resprouting of scattered *Populus*, can produce a POTR-PIPO or POTR-PSME layer type. Both of these can progress to a pine or Douglas-fir layer group more quickly than the POTR-POTR layer type.

Although relatively uncommon in PSME/PHMA, the POTR l.g. can be found on old landslides, the leeward sides of windswept ridges, and possibly elsewhere. It could develop on any site supporting *Populus tremuloides* if competing conifers are killed. Only four stands in this layer group have been found; all were in the POTR-POTR layer type. Stand ages ranged from 18 to 75 years; none showed recent invasion by conifers even though the oldest stand was bordered by an adequate seed source of *Pseudotsuga*.

PINUS PONDEROSA LAYER GROUP (PIPO L.G.)

By definition, *Pinus ponderosa* occurs throughout the PIPO phase of PSME/PHMA and, unless planted, is absent in the PSME and PAMY phases. *Pinus ponderosa* is the only major seral tree species found throughout the PIPO phase and is often prevalent in old-growth stands, yet it seldom colonizes recent clearcuts. Poor dispersion of the heavy seed and unsuitable seedbeds limit the pine regeneration. Distance to seed source and infrequent cone crops are often responsible for a scarcity of seed. Logging and high-intensity burning stimulate several shrub and herb layer species, which can quickly dominate potential pine seedbeds. As a result, natural establishment of *P. ponderosa* in large clearcuts is often slow and sporadic.

The PIPO layer group consists of two layer types in the PSME/PHMA h.t (fig. 3). Both of these layer types are quite common and were extensively sampled. The PIPO-PIPO layer type has resulted mainly from plantations, especially where the dominant size class is now saplings or small poles (appendix A). PIPO-PIPO in the larger size classes resulted either from shelterwood and seed-tree cuts or wildfire within the past 50 years (fig. 5). PIPO-PSME layer types were dominated mainly by pole-size or larger trees. This layer type resulted mostly from wildfire 50 to 100 years ago.

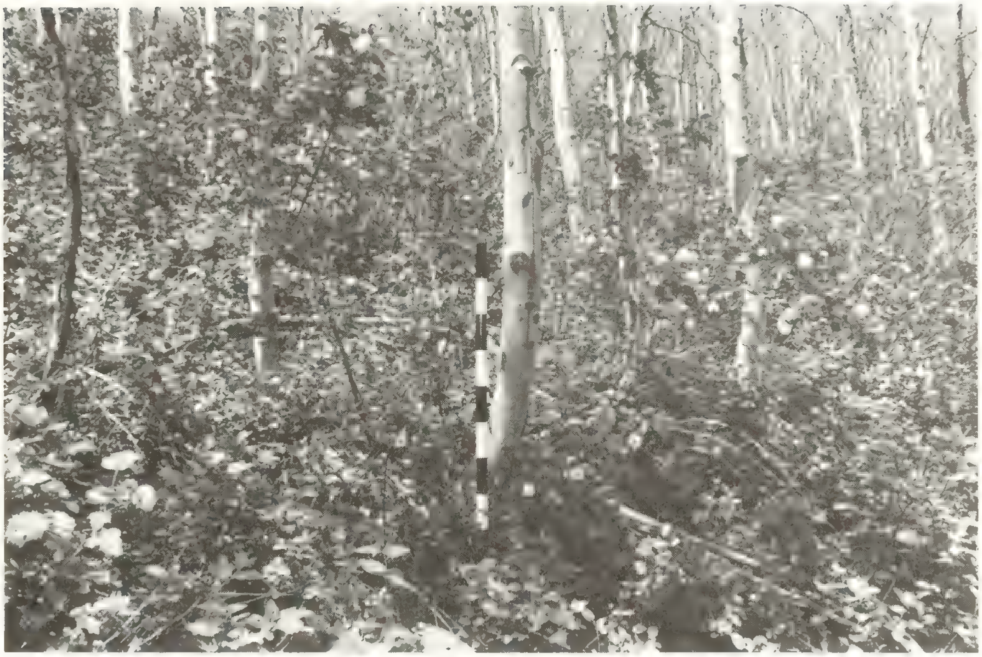

Figure 4—A pole POTR-pole POTR tree layer type west of Idaho City, ID, in 1985. This area was cleared by wildfire in 1931. The *Populus* probably was here prior to the fire and simply resprouted. This clone has been increasing its size and now covers several acres. An occasional *Pseudotsuga* seedling is the only conifer present after 5 decades. Both *Pinus ponderosa* and *Pseudotsuga* seed sources occur within 200 feet (61 m).

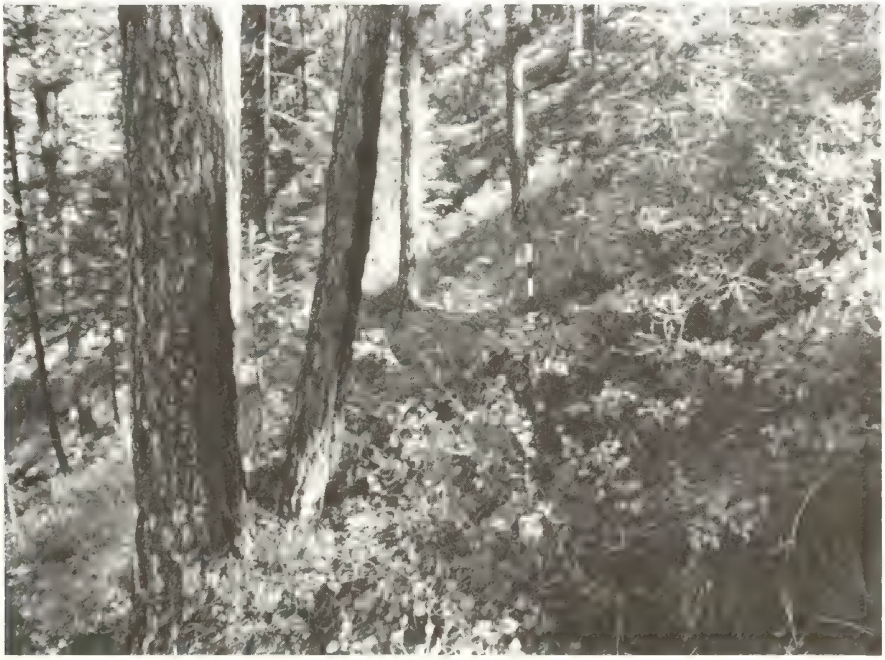

Figure 5—A pole PIPO-mature PIPO tree layer type in the Andersen Creek drainage east of Crouch, ID, in 1979. This site experienced a surface fire in 1931, and most of the *Pinus ponderosa* survived. Since then *Pseudotsuga* saplings have accumulated in the understory and created fuel ladders into the pine canopy. The entire stand was lost to wildfire in 1986.

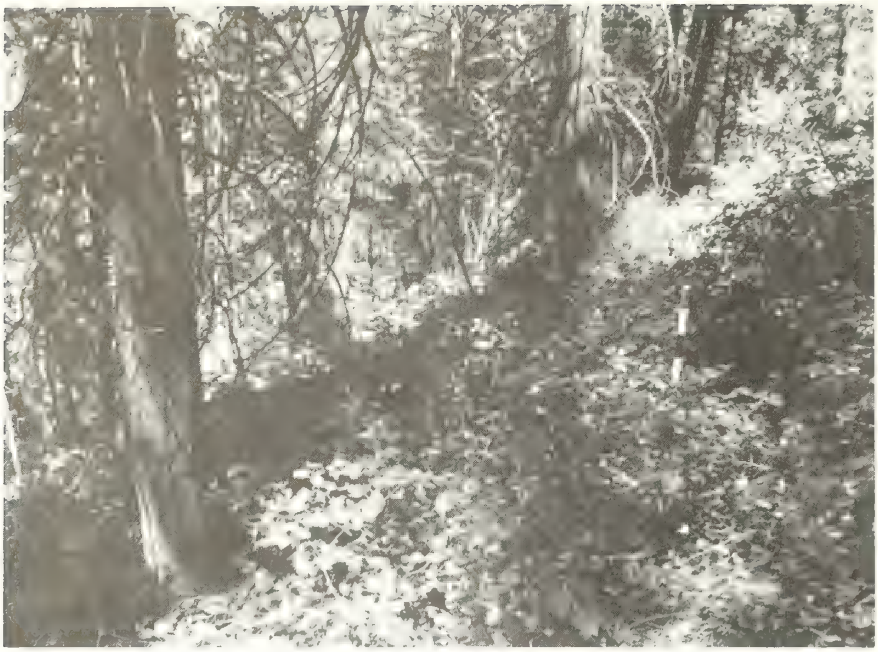

Figure 6—A pole PSME-mature PSME tree layer type southwest of Idaho City, ID, in 1979. This 90-year-old stand of *Pseudotsuga* apparently originated following a severe wildfire in about 1889. It has escaped subsequent wildfire as evidenced by the many dead tree branches still attached near ground level. Because no species replacement is possible, this tree layer has reached climax in one generation.

Prior to settlement by Euroamericans, wildfire burned PSME/PHMA sites at frequent intervals. In west-central Idaho, fire frequency ranged from about every 13 years in the dry extremes of PSME/PHMA to about every 22 years in the moist extremes (Steele and others 1986). Wildfires at these frequencies were most likely low-intensity surface fires, that killed most of the young *Pseudotsuga* in the stand but not the more fire-resistant pine (Arno 1976). Even young pines are fairly resistant to low-intensity surface fires, and the eventual result was an accumulation of pine dominating the site. Today, in the absence of frequent surface fires, these PIPO-PIPO layer types are difficult to achieve naturally but are being replaced by many pine plantations. Unlogged sites that now burn infrequently often develop high coverages of *Pseudotsuga*, resulting in the PIPO-PSME layer type. Selective cutting of the pine in PIPO-PSME has quickly advanced succession to the PSME layer group.

PSEUDOTSUGA MENZIESII LAYER GROUP (PSME L.G.)

Pseudotsuga is the only tree species that occurs throughout the range of PSME/PHMA and, being the most tolerant, acts as the climax species. In general, climax species are more difficult to establish than seral species, and *Pseudotsuga* is no exception. Most plantings of *Pseudotsuga* have failed in the PSME/PHMA h.t., and natural regeneration is usually slow to establish and appears to need protection from sun and wind. It is likely that most existing stands of *Pseudotsuga* developed gradually beneath the canopy of either seral trees or shrubs.

As climax, the PSME layer group consists of only one layer type, PSME-PSME (fig. 3). This layer type can occur in nearly pure stands of sapling, pole, and mature trees as well as old-growth. Regardless of tree size, the PSME-PSME layer type is considered closest to climax on a successional scale because no successional replacement of tree species will occur and the climax species is already dominant (fig. 6). Compared to other tree layer types in PSME/PHMA, PSME-PSME generally has the greatest hazard potential for catastrophic fire, insects (spruce budworm), and disease (dwarf mistletoe). Silvicultural options also become more limited due to the prevalence of these hazards and the scarcity of seral tree species in the stand.

MANAGEMENT IMPLICATIONS

The following management implications were derived from data and repeated field observations taken during this study and the habitat type study (Steele and others 1981). Because of the often small sample size of the data set and the minimal amount of field testing and user response, the reader should exercise caution in implementing trace findings. Nevertheless, trends reflected by these data are logical and support the management implications.

Pocket Gophers—It has long been known that pocket gophers (*Thomomys talpoides*) can damage pine plantations (Dingle 1956; Moore 1943). Reasons for this damage have been studied at length. In summarizing gopher-related studies, Teipner and others (1983) suggest that gopher damage to young pines may be related to amount

Table 4—Occurrence of pocket gopher mounds following various site disturbances in the PSME/PHMA h.t., PIPO phase

Site treatment	Number of sites	Mound occurrence[1]
Clearcut, broadcast burned, or stand destroyed by wildfire	28	25(68) - 7(37)
Clearcut, broadcast burned, and scarified	6	50(65) - 7(21)
Clearcut and contour terraced	9	11(20) - 18(13)
Clearcut, unburned, and scarified	17	71(129) - 11(10)
Partial cut and scarified	5	60(138) - 15(13)
Clearcut and no site preparation	18	11(25) - 10(12)

[1] Expressed as: percentage constancy (average number/acre) - average years since disturbance of sites with mounds (average years since disturbance of sites without mounds).

and composition of plant species as well as gopher density. Our studies indicate that plant species composition can vary with type of site preparation for tree planting which, in turn, may influence gopher populations. Therefore, pocket gopher mounds were tallied (Richens 1965) in our sample plots and then summarized by site treatment.

Although gopher mounds are common on disturbed sites in PSME/PHMA, they occur most frequently in cutover areas that have been well scarified but not burned (table 4). Gopher mounds also occur most frequently on unburned scarified areas in several other habitat types (Steele and Geier-Hayes 1984, 1985, 1986, 1987b). The gophers, of course, do not respond directly to the site treatment but rather to the resulting vegetation. Thorough scarification, either by machines or heavy livestock use, generates early seral herbaceous layers which likely stimulate gopher populations. In contrast, burning without scarification can result in a depauperate herb layer by generating a dense shrub layer. Burning can also result in mid- to late seral herbaceous layers, which apparently have less appeal to gophers. (See herb layer section for further discussion.)

Planted Tree Establishment—Planted sites were identified from plantation signs and obvious rows of even-aged trees. Seedling survival was estimated in percentage and recorded for each site preparation technique. Site preparation included no preparation, hand scalps, scarification with and without burning, and contour terraces. Hand scalping was grouped with no preparation because it usually did not reduce long-term competition and because it could not always be recognized in older plantations. Scarification treatments usually resulted from stripping, pile and burn operations, or extensive machinery traffic during logging. Scarification treatments are uncommon, however, on many of the steeper slopes associated with this habitat type.

Contour terraces varied in width from 2 to 3 feet on more gentle terrain to 6 to 8 feet on the steeper slopes. During the 1950's and 1960's, terraces were used mainly for establishing ponderosa pine seedlings in areas that had been burned by wildfire and had become dominated by tall shrubs. Seedling survival was generally high. Because some terraces were installed on unstable hillsides the practice was discontinued. These terraces result in a horizontal tread across the slope and a large amount of soil displacement. Terraces built with large bulldozers were wide and displaced considerable soil but ideally were widely spaced on the slope so as to reduce erosion. Contour ditches appear to have the same effect on pine survival as contour terraces, thus both treatments are grouped in this report. In contrast, the ditches were usually built with a large plow and resulted in much less soil displacement than the terraces. Ditches have proven to be effective where the residual plant competition is low in height, such as pinegrass, elk sedge, spirea, and common snowberry. Contour ditches are also effective in ninebark when the shrub layer is relatively low. Unfortunately, use of contour ditches was also discontinued when the terraces earned disfavor.

In the PIPO phase of PSME/PHMA, survival of planted *Pinus ponderosa* (table 5) was greatest (about 76 percent after 13 years) on contour terraces or ditches (fig. 7). These treatments apparently improve the soil moisture regime by collecting runoff and by removing the stored seed and root crowns of competing plant species. Improved survival of planted pines on contour terraces and ditches has also been noted in other Douglas-fir habitat types (Curtis and Coonrod 1960; Hall and Curtis 1970; Steele and Geier-Hayes 1984, 1986). But this treatment does not necessarily improve survival in grand fir habitat types where soil moisture is usually adequate for ponderosa pine (Steele and Geier-Hayes 1985, 1987b).

Other site treatments, such as burning and scarification, can result in substantially lower pine survival than contouring (table 5). These treatments do not decrease competing vegetation, especially rhizomatous species, as effectively as contour terraces or ditches and do not concentrate soil moisture for the tree seedling. With burning, plant competition is often increased by stimulating certain species to sprout vigorously or to germinate from buried seed. Unless plantations are established the spring following the burning, the planted trees are at a serious disadvantage as the competition increases. Scarification usually destroys aboveground portions of competing vegetation, and some shallow rooted species, but often allows more deeply rooted species to resprout and stimulates some species to germinate from buried seed. As in most habitat types, plantations with little or no site preparation tend to have the poorest survival (table 5). Lack of any disturbance simply allows existing competition to strengthen their dominance without interruption.

Table 5—Success of tree plantations by site treatment in the PSME/PHMA h.t, PIPO phase

Tree species	Site treatment[1]			
	None (includes hand scalps)	Broadcast burning	Scarified unburned (includes stripping)	Contour terraces (includes ditching)
	Survival of planting, percent (average age)[2]			
PIPO	20(26) *n* = 5	40(20) *n* = 2	28(14) *n* = 8	76(13) *n* = 11
PSME	0(16) *n* = 1	—	—	—
	Average age to breast height, years			
Planted[3]				
PIPO	10 *n* = 4	8 *n* = 2	9 *n* = 6	8 *n* = 9
PSME	—	—	—	—

[1] *n* = number of sample sites.

[2] Plantings less than 4 years old were omitted; complete plantation failures were not always recognized and multispecies plantings could not be sampled for survival.

[3] Nursery years are not included.

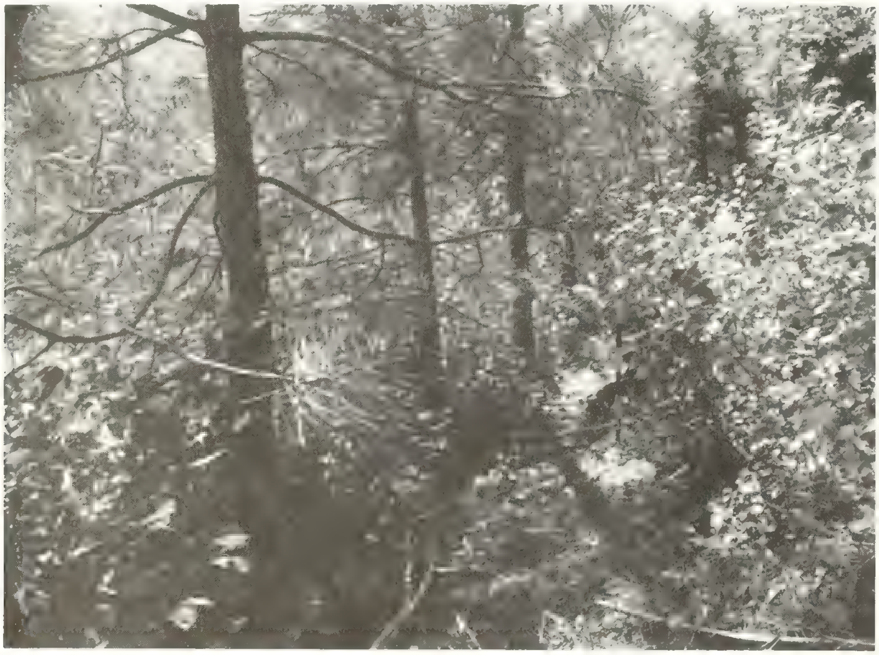

Figure 7—An old plantation of *Pinus ponderosa* on contour terraces. During the 1960's many of these plantations were installed on contour terraces and ditches in PSME/PHMA. They have proven highly successful for pine regeneration where soil stability can be maintained.

The survival percentages in table 5 may differ from Ranger District records for two reasons. First, the data reflect planting attempts over many years and many early planting failures were due to factors other than site treatment and habitat type. Second, the data reflect seedling success over the past 10 to 30 years whereas District records are generally maintained for only a few years after planting and do not reflect the long-term effects of site and competition. Our figures are not necessarily the highest possible survival rates because, occasionally, high survival has been achieved in several treatment categories. Our survival rates are best interpreted as a relative probability of success rather than expected percentage of survival.

Age to Breast Height—The years required for a tree to reach breast height (4.5 feet [1.4 m]) can be a critical factor in estimating growth and yield parameters of forest stands as well as seedling success against competing vegetation. Normally an estimated constant is used for a given species regardless of site. Yet for some species, sample data have shown considerable variability in breast height ages between habitat types and even between site treatments within a habitat type. In PSME/PHMA, breast height age for planted *Pinus ponderosa* is about 8 to 9 years regardless of site treatment (table 5). A lack of site preparation, however, may extend breast height age to 10 years and in some cases up to 13 years.

Date are scarce for planted *Pseudotsuga* in the PIPO phase but a few natural seedlings reached 4.5 feet (1.4 m) in about 14 years.

Snow Damage to Pine Plantations—Extensive snowpack damage to ponderosa pine plantations was previously noted in the grand fir/mountain maple habitat type (Steele and Geier-Hayes 1985) and led to an assessment of similar damage in PSME/PHMA. The damage is sustained mainly by trees greater than 4.5 feet (1.4 m) tall. It varies from stripped lateral branches and bent terminals to permanent 90-degree angles in the main stem and entire saplings pushed into semiflattened positions. Stem internodes indicate that, once damaged, the pine's growth rate is reduced for a year or more, making the young tree more vulnerable to shrub competition. With lodgepole pine, Rehfeldt (1987) noted a similar loss in growth rate of 22 percent. Long-term snow records suggest that subsequent damage may occur about every 4 years, causing accumulated deformities (Megahan and Steele 1987). In spring, these bent, stunted trees remain beneath the snow longer than undamaged trees and during prolonged snowmelt can suffer increased mortality from the brown-felt blight (*Neopeckia coulteri*).

In PSME/PHMA, most pine saplings situated below 5,200 feet (1,585 m) in elevation escape serious snow damage although the main stems and lateral branches may be temporarily deformed at elevations as low as 4,800 feet (1,463 m). As elevation increases above 5,200 feet (1,585 m), damage potential also increases. But damage may be less severe on northerly aspects (between 340° and 20° azimuth) or under certain site conditions described below. Slope steepness is a relatively minor variable because most slopes in PSME/PHMA are steep enough to cause snow movement. At the uppermost elevations of PSME/PHMA, snow damage is apt to occur on any aspect but can be alleviated by certain conditions. For instance, pine plantations near ridgetops may escape snow damage within the hazard zone. Likewise, plantations that are well shaded in early spring by a nearby ridge or adjacent old-growth stand may escape damage. Sites with high stumps and large logs which limit snow movement can also reduce snow hazards. Proper location and treatment of cutting units can exploit these advantages where high damage potential exists.

In contrast, potential snow damage can be increased by contour terraces. In steep terrain, these terraces are often quite wide and accumulate more snow than adjacent slopes. Terrace cutbanks create a steepened sliding surface that exacerbates snow movement. The pines planted closest to the cutbank are most apt to be damaged while those nearest the fill slope often escape damage.

Extent of snow damage within plantations can vary from scattered individual trees at lower elevations to virtually all trees at the upper elevations. Trees having only light damage (bent terminals) generally recover as described by Oliver (1970) unless repeatedly damaged. Severely damaged trees probably could recover but are usually situated so as to receive repeated snow damage, making full recovery unlikely.

Proper genetic seed source is a critical factor in snow damage susceptibility and recovery (Rehfeldt and Cox 1975). In central Idaho, ponderosa pine displays a number of growth-related variations that can be viewed as genetic adaptation (Rehfeldt 1986). In general, plantations from lower elevation seed sources have higher growth potentials, longer periods of annual elongation, and are more apt to sustain permanent damage in the snow hazard zone. Trees from upper elevation seed sources display less growth potential, shorter periods of annual elongation, and tend to sustain less snow damage and recover more readily. In some areas, upper elevational limits of ponderosa pine may not be due to low temperatures but rather deep snowpacks. Consequently, at upper elevations where the pine occurs naturally in only minor amounts, even pine plantations of the proper seed source may experience reduced stocking levels and may not be a major component of the stand by rotation age. Selecting seed origins having inheritable stockiness (Silen and Rowe 1971) and planting the seedlings at greater densities may overcome this problem, but that has yet to be proven. Recognizing snow damage potential can be difficult in many areas, but it is an important consideration when planting ponderosa pine on PSME/PHMA sites above 5,200 feet (1,585 m) in elevation.

Growth and Yield Capability—Height-age data of free-growing trees, usually in clearcuts or burns, were collected during the course of this study. These data provided growth information for the younger age classes of major tree species in PSME/PHMA. Similar data in older age classes were taken from dominant or codominant trees in old-growth stands during this study and the habitat type classification study (Steele and others 1981). Increment cores of these older trees were examined for evidence of suppression. If the core indicated past suppression, or if it was too far from the pith to allow a confident estimate of total age, the tree was rejected. Remaining data were used to estimate site index and yield capability.

The basis for estimating site index and yield capability are from three sources. The *Pseudotsuga* site index was plotted from Monserud's (1985) site curves but because no yield tables exist for *Pseudotsuga*, Brickell's (1970) ponderosa pine yield curve was used. The *Pinus ponderosa* site index and yield capability were derived from Brickell's (1970) site curves, which are a conversion to a 50-year base age from Lynch (1958).

Growth and yield capabilities of the PSME/PHMA h.t., PIPO phase are shown in table 6. Ponderosa pine apparently produces only slightly more volume than Douglas-fir. But if Douglas-fir yield tables were developed, yield differences between the two species may actually be greater.

Table 6—Growth and yield characteristics of trees in the PSME/PHMA h.t., PIPO phase

Tree species	Number of site trees	Site index (50-year base)	Number of stands	Yield capability
				Ft³/acre/year
Pseudotsuga menziesii	*n* = 24	60±6[1]	*n* = 24	83±13
Pinus ponderosa	*n* = 25	62±4	*n* = 14	84±8

[1] 95 percent confidence intervals.

The Shrub Layer

Shrub layer succession is more diverse and less easily interpreted than that of the tree layer. Environmental variation within the habitat type also contributes to this diversity. The dry extreme of PSME/PHMA h.t., PIPO phase usually merges with the Douglas-fir/white spiraea (PSME/SPBE) habitat type and the moist extreme merges with grand fir/mountain maple (ABGR/ACGL) or Douglas-fir/mountain maple (PSME/ACGL). Shrub layer succession near these extremes often resembles that of the adjacent site more than a modal PSME/PHMA site.

The important shrub layer species in PSME/PHMA are listed in table 7. Among the 151 shrub layers sampled in the PSME/PHMA h.t., PIPO phase, there are seven major seral species and nine alternates. The alternate species often occur in only part of the habitat type and for classification purposes are grouped with more widespread species having similar successional strategies and amplitudes. For instance, *Ceanothus sanguineus,* which occurs at lower elevations in PSME/PHMA, is grouped with *C. velutinus* because of similar seed storage capabilities, shade tolerances, and responses to burning; *Symphoricarpos oreophilus* is grouped with *Amelanchier* because both species are disseminated mainly by rodents and birds, are nonrhizomatous, and can persist beneath a moderately dense tree canopy. *Philadelphus* is grouped with *Salix* because both species tend to colonize bare mineral soil, are nonrhizomatous, and have moderate shade tolerance. *Acer* and *Vaccinium* were grouped with *Physocarpus* as climax species. A few other taxa such as *Rosa* and *Berberis* were only occasionally well represented and were not used for classification purposes.

Table 7—Occurrence and roles of major shrub species in the PSME/PHMA h.t. in central Idaho

ADP No.	Species	Abbreviation	Role[1]	
			PIPO phase	PSME phase
102	*Acer glabrum*	ACGL	(C)	(c)
105	*Amelanchier alnifolia*	AMAL	S	(S)
203	*Berberis repens*	BERE	c	(c)
107	*Ceanothus velutinus*	CEVE	S	(S)
198	*Ceanothus sanguineus*	CESA	(S)	-
173	*Cercocarpus ledifolius*	CELE	-	(S)
119	*Philadelphus lewisii*	PHLE	(S)	(s)
122	*Physocarpus malvaceus*	PHMA	C	C
123	*Prunus emarginata*	PREM	S	a
124	*Prunus virginiana*	PRVI	S	(S)
128	*Ribes cereum*	RICE	S	S
131	*Ribes viscosissimum*	RIVI	(S)	(s)
136	*Rubus parviflorus*	RUPA	(S)	-
137	*Salix scouleriana*	SASC	S	(s)
142	*Spiraea betulifolia*	SPBE	S	(S)
143	*Symphoricarpos albus*	SYAL	(S)	(s)
163	*Symphoricarpos oreophilus*	SYOR	S	S
146	*Vaccinium globulare*	VAGL	(C)	-

[1] S = major seral
s = minor seral
C = major climax
c = minor climax
a = accidental
( ) = occurs in only part of the phase, usually the moister portion or the warmer-drier portion.

Relative successional amplitudes of major shrub species in PSME/PHMA provide the basis for shrub layer classification and are shown in figure 8. These amplitudes were derived from many field observations and sample data (appendix B-1). They are meaningful only in a relative sense because there is no scale for measurement. Ideally, relative amplitudes should be established through studies of many permanent plots over many decades, but rarely is such a study ever attempted. Consequently, accuracy of relative amplitudes (fig. 8) varies from well-established trends (as in the tree layer) to the author's best guess. The certainty of this accuracy is greatest for the species farthest apart (fig. 8). For example, *Ceanothus* and *Ribes* clearly have less successional amplitude than *Physocarpus* (fig. 8), but the relative amplitudes of *Salix* versus *Prunus* are less certain. Consequently, when determining relative amplitudes one must use the "philosophy of successive approximations" (Poore 1962) as a scientific basis for developing hypotheses for each species followed by testing through field observation and data analysis.

From the relative amplitudes (fig. 8), a succession classification diagram for shrub layers is easily constructed (fig. 9). The classification consists of seven shrub layer groups and 28 layer types (fig. 9). Of the 28 possible layer types, 23 occur in the present data set (fig. 9). The remaining five layer types may be found with more reconnaissance, may appear only after uncommon disturbances (or disturbance combinations), or may be rare under any circumstance.

The classification diagram (fig. 9) is easily converted to a systematic key for field use (table 8). Indicator species (of layer groups) appearing early in the key have the least successional amplitude and so have greater indicator value than species with more amplitude, which appear progressively later in the key. This same ranking of

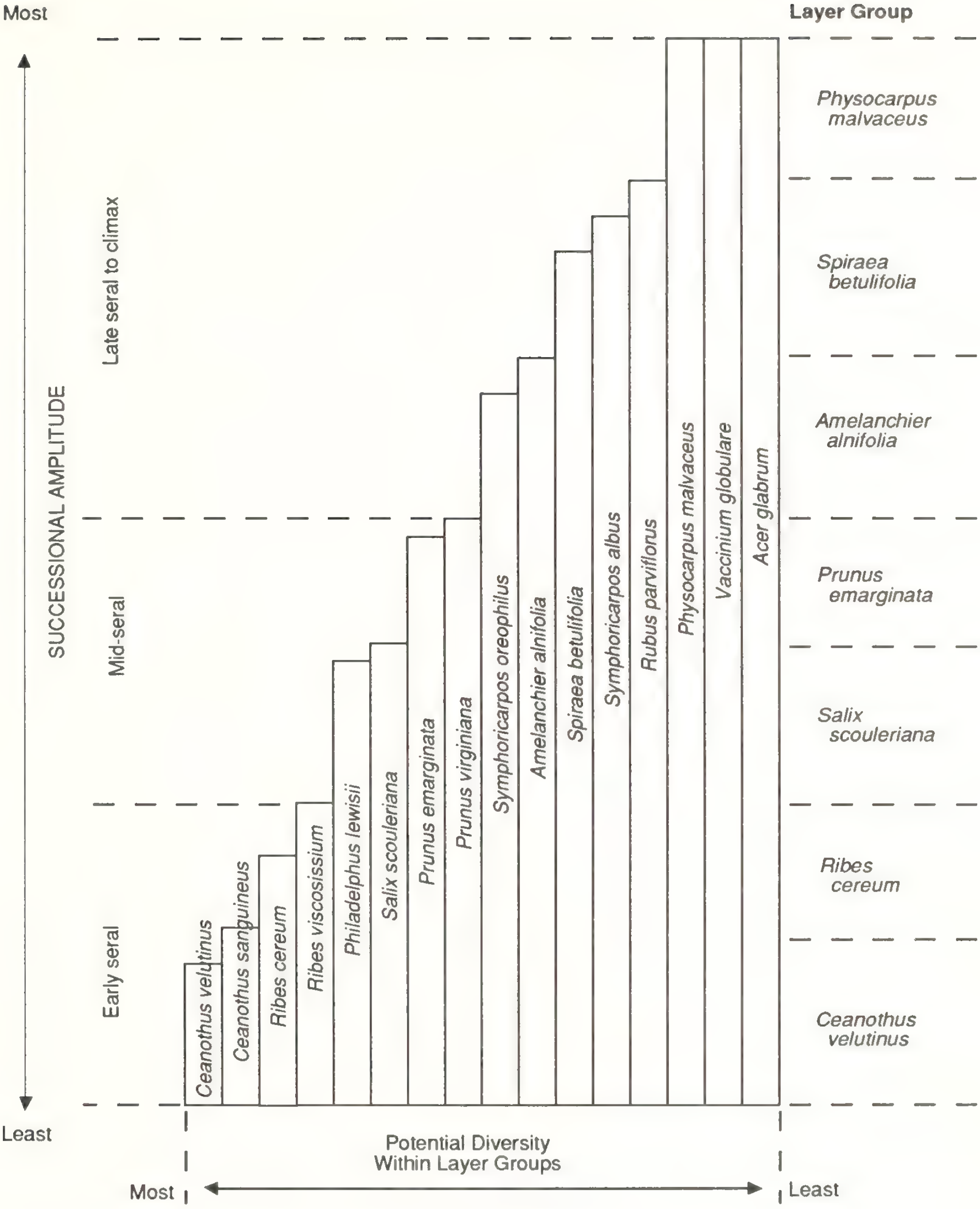

Figure 8—Relative successional amplitudes of important shrub species in the PSME/PHMA h.t., PIPO phase.

indicator value is used to select the dominant indicator for layer types when several species codominate the site. Alternate indicator species appear with their appropriate primary indicator throughout the key (table 8).

The range of years since disturbance of sampled layer types appears in appendix B-1; averages are given when three or more known ages exist per layer type. The low extreme of each range is meaningless because any layer type could have been recently disturbed; in these cases only disturbance intensity would vary between layer types. The upper yearly extremes and averages, which may reflect progression through several layer types, show a gradual though sporadic increase from left to right into successionally older shrub layers. This general progression of both years and layer types demonstrates that both entities delineate time, though in different ways. Years since last disturbance can be misleading, however, because some shrub layers were not caused by the last disturbance but merely survived it. This is particularly true with disturbances of low intensity.

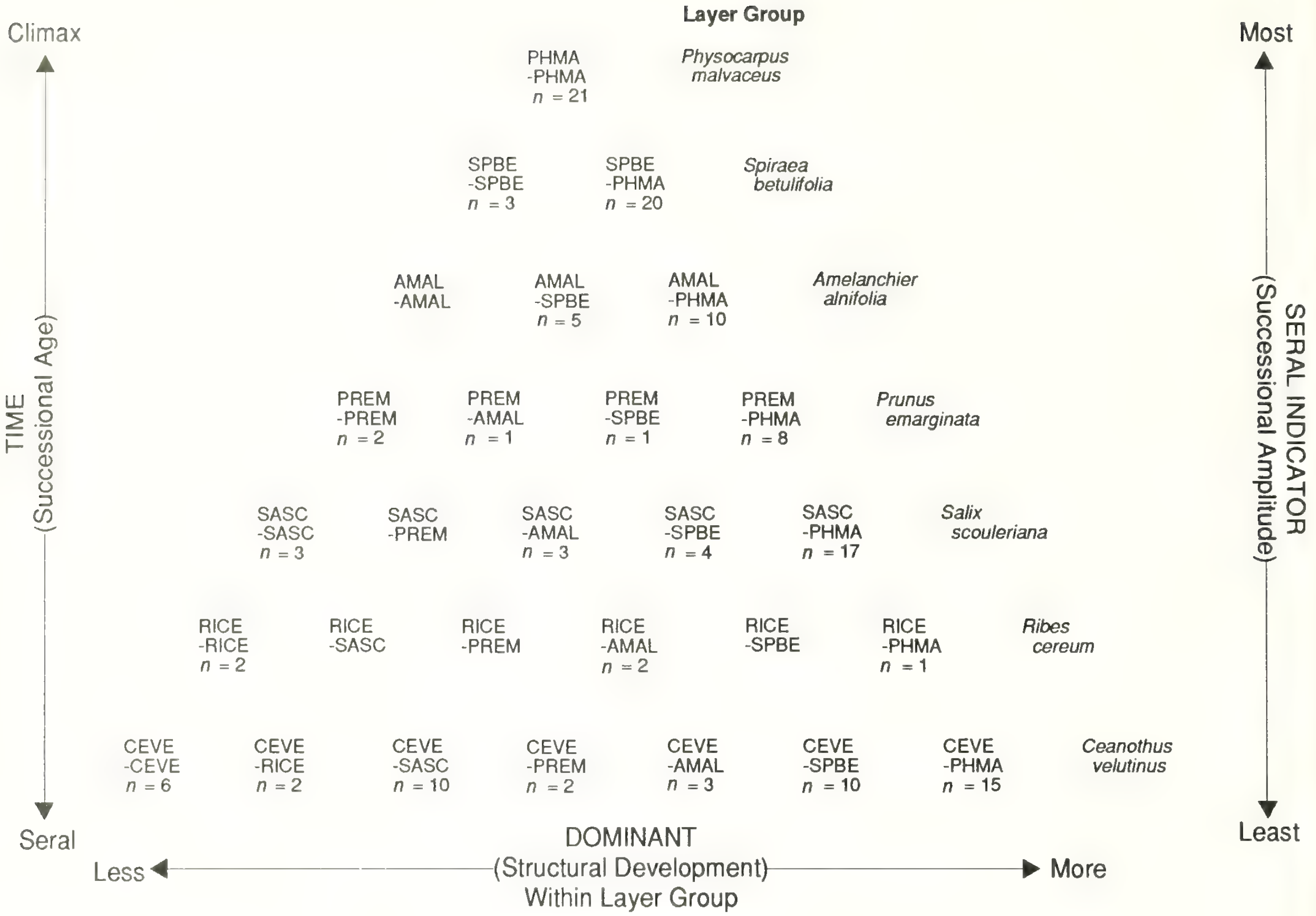

Figure 9—Succession classification diagram of the shrub layer in the PSME/PHMA h.t., PIPO phase (*n* = number of samples in each layer type).

Table 8—Key to shrub layer groups and layer types, with ADP codes, in the PSME/PHMA h.t., PIPO phase

Key	Result	ADP codes
1. *Ceanothus velutinus* (incl. *C. sanguineus*) well represented (≥5%)[1] (Choose first condition that fits)	CEVE Layer Group	107
1a. *Ceanothus* spp. dominant	CEVE-CEVE Layer Type	107.107
1b. *Ribes* spp. dominant or codominant	CEVE-RICE Layer Type	107.128
1c. *Salix scouleriana* dominant or codominant	CEVE-SASC Layer Type	107.137
1d. *Prunus* spp. dominant or codominant	CEVE-PREM Layer Type	107.123
1e. *Amelanchier* (incl. *Symphoricarpos oreophilus)* dominant or codominant	CEVE-AMAL Layer Type	107.105
1f. *Spiraea* (incl. *Symphoricarpos albus* and*Rubus parviflorus)* dominant or codominant	CEVE-SPBE Layer Type	107.142
1g. *Physocarpus* dominant or codominant	CEVE-PHMA Layer Type	107.122
1. *Ceanothus* poorly represented (<5%)	2	
2. *Ribes cereum* (incl. *R. viscosissimum*) well represented (≥5%) (Choose first condition that fits)	RICE Layer Group	128
2a. *Ribes* spp. dominant	RICE-RICE Layer Type	128.128
2b. *Salix scouleriana* dominant or codominant	RICE-SASC Layer Lype	128.137
2c. *Prunus* spp. dominant or codominant	RICE-PREM Layer Type	128.123
2d. *Amelanchier* (incl. *Symphoricarpos oreophilus*) dominant or codominant	RICE-AMAL Layer Type	128.105
2e. *Spiraea* (incl. *Symphoricarpos albus* and *Rubus parviflorus*) dominant or codominant	RICE-SPBE Layer Type	128.142
2f. *Physocarpus* dominant or codominant	RICE-PHMA Layer Type	128.122
2. *Ribes* spp. poorly represented (<5%)	3	
3. *Salix scouleriana* well represented (≥5%) (Choose first condition that fits)	SASC Layer Group	137
3a. *Salix* dominant	SASC-SASC Layer Type	137.137
3b. *Prunus* spp. dominant or codominant	SASC-PREM Layer Type	137.123
3c. *Amelanchier* (incl. *Symphoricarpos oreophilus*) dominant and codominant	SASC-AMAL Layer Type	137.105
3d. *Spiraea* (incl. *Symphoricarpos albus* and *Rubus parviflorus*) dominant or codominant	SASC-SPBE Layer Type	137.142
3e. *Physocarpus* dominant or codominant	SASC-PHMA Layer Type	137.122
3. *Salix* poorly represented (<5%)	4	
4. *Prunus emarginata* (incl. *P. virginiana*) well represented (≥5%) (Choose first condition that fits)	PREM Layer Group	123
4a. *Prunus* spp. dominant	PREM-PREM Layer Type	123.123
4b. *Amelanchier* (incl. *Symphoricarpos oreophilus)* dominant or codominant	PREM-AMAL Layer Type	123.105
4c. *Spiraea* (incl. *Symphoricarpos albus* and *Rubus parviflorus*) dominant or codominant	PREM-SPBE Layer Type	124.142
4d. *Physocarpus* dominant or codominant	PREM-PHMA Layer Type	123.122
4. *Prunus* poorly represented (<5%)	5	
5. *Amelanchier* (incl. *Symphoricarpos oreophilus)* well represented (≥5%) (Choose first condition that fits)	AMAL Layer Group	105
5a. *Amelanchier* (incl. *Symphoricarpos oreophilus*) dominant	AMAL-AMAL Layer Type	105.105
5b. *Spiraea* (incl. *Symphoricarpos albus* and *Rubus parviflorus*) dominant or codominant	AMAL-SPBE Layer Type	105.142
5c. *Physocarpus* dominant or codominant	AMAL-PHMA Layer Type	105.122
5. *Amelanchier* and *Symphoricarpos* poorly represented (<5%)	6	
6. *Spiraea betulifolia* (incl. *Symphoricarpos albus* and *Rubus parviflorus*) well represented (≥5%) (Choose first condition that fits)	SPBE Layer Group	142
6a. The above species dominant	SPBE-SPBE Layer Type	142.142
6b. *Physocarpus* dominant or codominant	SPBE-PHMA Layer Type	142.122
6. The above species poorly represented (<5%)	7	
7. *Physocarpus malvaceus* well represented (≥5%)	PHMA Layer Group	122
7a. *Physocarpus* dominant	PHMA-PHMA Layer Type	122.122
7. *Physocarpus* poorly represented (<5%)	depauperate or unclassified shrub layer	

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[1] "Well represented" means canopy coverage ≥5 percent. "Dominant" refers to greatest canopy coverage regardless of height, "codominant" refers to nearly equal canopy coverage. When keying to layer type, choose first condition that fits.

CEANOTHUS VELUTINUS LAYER GROUP (CEVE L.G.)

Ceanothus velutinus is a shade-intolerant nonrhizomatous shrub. It has no apparent means of long-distance seed dispersal, but some of its seed are likely eaten and transported by small birds. Chipmunks were frequently seen feeding on the fruits and may provide short-distance dispersal. Most seed, however, simply falls to the ground and can remain viable in the soil and duff for at least 200-300 years (Gratkowski 1962) and possibly over 500 years (Zavitkovski and Newton 1968). The small hard seeds germinate readily following burning, and the young plants can grow 4 to 6 feet tall in about 10 years. *Ceanothus* density is often directly proportional to burning intensity, and severely burned areas can produce thickets that discourage access by man and livestock. In some areas, particularly to the north and east of Banks, ID, *C. sanguineus* occurs instead of *C. velutinus*, but its successional role appears similar. On slopes overlooking the Snake River canyon, neither species of *Ceanothus* is present on many PSME/PHMA sites; reasons for this absence are not known. Elsewhere in the PSME/PHMA h.t., PIPO phase, at least one species of *Ceanothus* is usually present either in the form of shrubs or seed. The occurrence of *Ceanothus* shrubs along roads and other disturbed areas usually indicates that viable *Ceanothus* seed exists on adjacent timbered sites where the shrubs are absent (Kramer 1984).

The CEVE layer group represents some of the most common early seral shrub layers in PSME/PHMA, especially in the PIPO phase. Here, all seven of the CEVE layer types that may occur were found (fig. 9). These layer types usually reflect various severities or frequencies of burning. Severe burns that kill existing shrubs are usually the least frequent and can produce the CEVE-CEVE layer type. Less severe burning of climax shrub layers can produce the CEVE-PHMA layer type. Various burning intensities of other seral stages may produce the other CEVE layer types (fig. 9) depending on the preburn species composition. Sometimes CEVE layer types will appear following light scarification (fig. 10), but their development is usually less dense. Severe scarification is likely to produce the CEVE-RICE layer type that usually has a sparse shrub canopy.

The CEVE layer types are perhaps the easiest to achieve following disturbance and in PSME/PHMA respond dependably to moderate or severe burning. Following severe burning a dense CEVE-CEVE layer type will develop and deter livestock and erosion. Moderate burning can result in a less dense canopy that provides shelter and nutrients for *Pseudotsuga* seedlings (Youngberg and others 1979). Some CEVE layer types have high forage value for deer and elk, and the nests of small birds were frequently found in these shrub layers. CEVE layer types in general can progress successionally to most other shrub layer groups, but the progression of individual stands to other layer types is determined by species composition and canopy cover (appendix B-2).

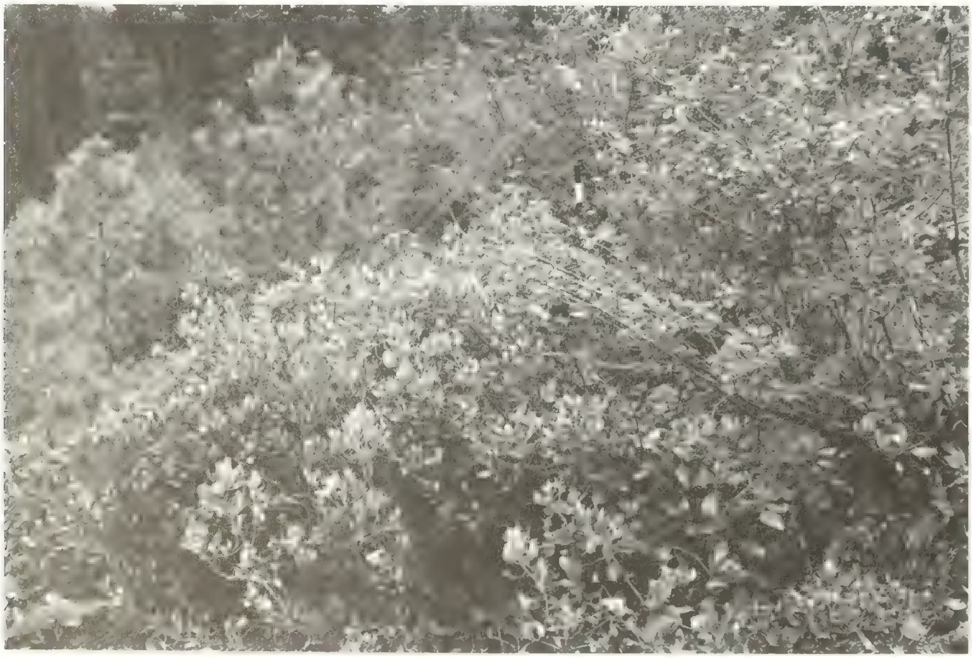

Figure 10—A CEVE-AMAL shrub layer type in the Bannock Creek drainage southeast of Idaho City, ID. This site was clearcut 17 years ago. The logging slash was pushed downslope with a bulldozer, causing light scarification. *Ceanothus* germinated from buried seed in response to the increased sunlight and soil disturbance. *Amelanchier* and *Symphoricarpos oreophilus* probably occurred here prior to logging and simply resprouted with renewed vigor. They now codominate the shrub layer.

RIBES CEREUM LAYER GROUP (RICE L.G.)

The RICE layer group is denoted mainly by *Ribes cereum*, but *R. viscosissimum* and small amounts of other *Ribes* species may be present. These *Ribes* are characteristically early seral nonrhizomatous shrubs, often the first to dominate well-scarified sites. Having a low tolerance for shade, they begin declining shortly after a canopy taller than their own develops. The *Ribes*, however, seem to maintain their coverages toward climax longer than *Ceanothus* and so are considered slightly less vulnerable to succession. Like *Ceanothus*, numerous seed of *Ribes* fall to the ground and remain viable in the soil and duff long after the parent shrubs have disappeared. But because *Ribes* have a fleshy fruit, many seeds are also dispersed by various birds and mammals. The *Ribes* seed, however, are not as ubiquitous on PSME/PHMA sites as are *Ceanothus* seed. Kramer (1984) found *Ribes* seed in only 6 percent of the old-growth PSME/PHMA sites as opposed to 75 percent for *Ceanothus*. *Ribes cereum* is known to have some allelopathic capability (Heisey and Delwiche 1983), but its effectiveness on PSME/PHMA sites has not been studied.

RICE layer types are uncommon in PSME/PHMA; only three out of the six possible layer types were found (fig. 9). These layer types generally result from various intensities of scarification. Thorough scarification that reduces the *Physocarpus* will likely result in a RICE-RICE layer type, whereas light scarification would result in RICE-PHMA. Because most slopes in PSME/PHMA are too steep for machine scarification, RICE layer types are uncommon even when adequate *Ribes* seed is present. RICE layer types usually result from scarification, which reduces existing shrubs; therefore these layer types have some of the lowest forage values for big game and the least competition for tree seedlings. The RICE layer types sampled are progressing toward the AMAL and PHMA layer groups (appendix B-3).

SALIX SCOULERIANA LAYER GROUP (SASC L.G.)

Salix scouleriana is a nonrhizomatous shrub that has high value for big-game browse (appendix B-1). It can also provide nesting and feeding habitat for small birds. *Salix* has light, windblown seeds that are dispersed in late spring, have a short-lived viability, and require moist mineral soil for germination (Brinkman 1974). Though only slightly tolerant of shade, its tall growth habit—up to 25 feet (7.6 m) in PSME/PHMA—enables it to persist in small openings on well-timbered sites. Its rapid sprouting ability allows it to recover quickly when tree competition is removed. In clearcuts, *Salix* may enhance *Pseudotsuga* establishment by protecting the site from sun and wind, but it is a formidable competitor of *Pinus ponderosa* seedlings. Having a low tolerance for shade, the pine must outgrow *Salix* in order to survive. This is barely possible because planted pine and *Salix* seedlings have similar growth rates for about the first 8 years in PSME/PHMA. But *Salix* sprouting from stumps can outgrow the pine in the first year, thus adjacent pine seedlings have little chance for survival. High densities of *Salix* in uncut stands may require mechanical or chemical treatment following clearcutting where pine plantations are a management objective. However, mechanical removal of large old-growth *Salix* can displace considerable soil. Also, *Salix* stems severed in the process may produce new plants if in contact with moist soil. Appropriate chemicals would control the *Salix* with less impact on the site.

The SASC layer group represents a mid-seral stage of shrub layer succession and consists of five layer types in PSME/PHMA (fig. 9). Four of these have been sampled. Much of this layer group, and especially the SASC-PHMA layer type, has resulted from severe wildfires that have occurred since the early 1900's. Many broadcast burn operations, however, do not burn hot enough to create an adequate seedbed for *Salix*. Such treatments usually generate a CEVE layer type that has little *Salix* and bypasses the SASC layer group during succession. Recently, SASC layer types have resulted from mechanical scarification in clearcuts, especially where exposed soil was mounded so as to trap water, thus creating well-watered seedbeds of mineral soil. This situation generally produces a SASC-SASC layer type. Most of the SASC layer types that were sampled are progressing toward SPBE- and PHMA-dominated layer types (appendix B-4).

PRUNUS EMARGINATA LAYER GROUP (PREM L.G.)

Prunus emarginata and the alternate indicator, *P. virginiana*, are moderately shade-tolerant shrubs. They generate many root sprouts and tend to form thickets that provide important food and cover for wildlife. Birds and mammals disperse the heavy flesh-covered seed in the fall. These seeds can remain viable in the soil and duff for many years (Kramer 1984). The seed has an embryo dormancy (Grisez 1974) that is offset by winter conditions. It germinates in early spring and probably responds best to broadcast burning. *Prunus emarginata* is more common in PSME/PHMA than is *P. virginiana* and appears to be slightly less shade tolerant.

PREM layer types represent mid-seral stages of shrub layer succession. All four layer types were found (fig. 9), but only the PREM-PHMA layer type is common. Although it is not known how all PREM layer types are formed, some obviously result from succession of CEVE layer types. Other PREM layer types appear to have been burned repeatedly by wildfire. Apparently, the *Ceanothus* that germinated after these fires has been reduced by shrub layer succession or had little seed stored in the soil at the time of the last fire. Still other PREM layer types exist on scarified sites, but these appear to be predisturbance shrub layers that merely survived the scarification. Although it is not yet known how PREM layer types can be generated directly, deep and thorough scarification or a chemical treatment is needed to remove these communities. It may also be possible to replace PREM layer types with CEVE layer types through severe burning if sufficient fuels exist. In this case, a CEVE-PRVI layer type is most likely to occur. Most PREM layer types that were sampled are progressing toward PHMA-dominated layer types (appendix B-5).

Although not widespread in PSME/PHMA, the PREM layer types have considerable value for wildlife. The fleshy fruits of *Prunus, Amelanchier, Rosa,* and *Symphoricarpos* can provide abundant food for grouse, numerous songbirds, small rodents, and black bear. Leaves and twigs of these shrubs are desirable browse for deer and elk. Although other shrub layers in PSME/PHMA have greater forage value for big game, the PREM layer types should have some of the highest values for birds and small mammals.

AMELANCHIER ALNIFOLIA LAYER GROUP (AMAL L.G.)

Amelanchier alnifolia is a nonrhizomatous shrub that occurs in many shrub layer types. It produces a fleshy fruit that is eaten by many birds and mammals which, in turn, disperse the seed. *Amelanchier* seedlings are often found growing in dense clusters as if from a seed cache made by a small rodent. The seedlings are mostly found in scarified soil under partial shade. This shrub has moderate to high forage value for deer, elk, and black bear (appendix B-1). Being of moderate shade tolerance, *Amelanchier* is often well represented on timbered sites as well as open brushfields. In full sun, *Amelanchier* grows rapidly, but beneath a tree canopy its coverage declines more slowly than most other seral shrubs, making it an indicator of late seral conditions.

Symphoricarpos oreophilus is considered an alternate indicator of the AMAL layer group because it is similar to *Amelanchier* in several ways and appears to have a similar successional amplitude. *Symphoricarpos oreophilus* must be distinguished from *S. albus*, which is a rhizomatous shrub and ecologically more similar to *Spiraea* than *Amelanchier*. *Symphoricarpos oreophilus* is a nonrhizomatous, moderately shade-tolerant shrub that is widespread in central Idaho. It produces a fleshy fruit which, though not eagerly sought, is likely dispersed by birds and mammals. Small *Symphoricarpos* seedlings are usually found growing in dense clusters as if from a cache made by a small rodent. This shrub has low to moderate forage value to large herbivores (appendix B-1) and is often well represented on timbered sites as well as deforested areas. Its deep root system enables it to survive most burning and scarification site treatments.

The AMAL layer group consists of three layer types, two of which were sampled (fig. 9). The AMAL-SPBE layer type occurred mainly in clearcut areas that had received either no site treatment or ineffective broadcast burns or scarification. This layer type likely existed prior to the clearcutting, although it may have been in less vigorous condition. The AMAL-PHMA layer type occurred on sites that had been either clearcut with no site treatment or had been deforested or underburned by wildfire 50 to 90 years ago. Thus it appears that AMAL layer types are mainly the result of successional advance rather than a particular site disturbance and can be maintained by clearcutting without additional treatment. All of these layer types were progressing toward SPBE and PHMA layer types (appendix B-6).

SPIRAEA BETULIFOLIA LAYER GROUP (SPBE L.G)

Spiraea betulifolia is a moderately shade tolerant rhizomatous shrub with root development well into the soil profile. Mechanical scarification and stripping seldom completely remove the *Spiraea* root system, which will resprout within the next growing season. *Spiraea* produces a small seed that has no obvious means of dispersal although occasional transport by small birds and rodents as well as strong winds seems likely. *Spiraea* seedlings are rarely found. Being rhizomatous, *Spiraea* usually grows in extensive colonies and has moderate forage value for mule deer and elk (appendix B-1). Its canopy cover declines quite slowly beneath a tree overstory, making it an indicator of late seral to climax conditions. In drier portions of PSME/PHMA, which often border the Douglas-fir/white spiraea habitat type, *Spiraea* may persist as a climax component of the shrub layer. In much of the PSME/PHMA habitat type, however, *Spiraea* gradually gives way to *Physocarpus*, making it a late seral indicator.

Symphoricarpos albus and *Rubus parviflorus*, though slightly more shade tolerant than *Spiraea*, are treated as successional equivalents. They, too, develop an extensive rhizomatous root system that usually resprouts following scarification of the site. These two species also provide moderate forage for deer and elk as well as some food for black bear (appendix B-1). In contrast to *Spiraea*, *Symphoricarpos albus* and *Rubus* do not occur throughout PSME/PHMA but are restricted to moister portions of the habitat type, particularly on finer textured or depositional soils. Like *Spiraea*, they may be part of the climax shrub layer in some situations but for classification purposes are treated as indicators of late seral conditions.

The SPBE layer group consists of two layer types, both of which were sampled (fig. 9). These two layer types result mainly from successional advance of early and mid-seral layer types containing *Spiraea*, *Symphoricarpos albus*, or *Rubus*. Out of 23 sample stands, only one SPBE layer type apparently resulted from a direct disturbance. Most of the others had been burned 30 to 125 years ago; many of these fires did not destroy the tree canopy, so that CEVE layer types either did not develop or declined rapidly. A few sample stands had experienced recent clearcuts with no site treatment, and the shrub composition remained unchanged. Although all SPBE-SPBE layer types were progressing toward SPBE-PHMA, only half of the SPBE-PHMA layer types appeared capable of progressing toward PHMA-PHMA (appendix B-7). The other half occurred on sites that appeared too dry for *Physocarpus* to outcompete *Spiraea* and had apparently reached their successional endpoint.

PHYSOCARPUS MALVACEUS LAYER GROUP (PHMA L.G.)

Physocarpus malvaceus is a shade-tolerant shrub that can form a layer above those of *Spiraea*, *Symphoricarpos*, and *Rubus* and gradually prevail as the climax dominant. Its coverage can be reduced by mechanical scarification, and repeated burning, but its potential for resprouting from an extensive root system can result in rapid recovery. *Physocarpus* produces a small, dry seed that can remain viable in the soil and duff (Kramer 1984). The seeds have no obvious means of transport but are likely dispersed by small birds and rodents.

Acer glabrum is a common associate of *Physocarpus* and may be well represented in climax stands. Occasionally *Vaccinium globulare* occurs as a climax component in the cool, moist extremes of the PSME/PHMA h.t. Both the

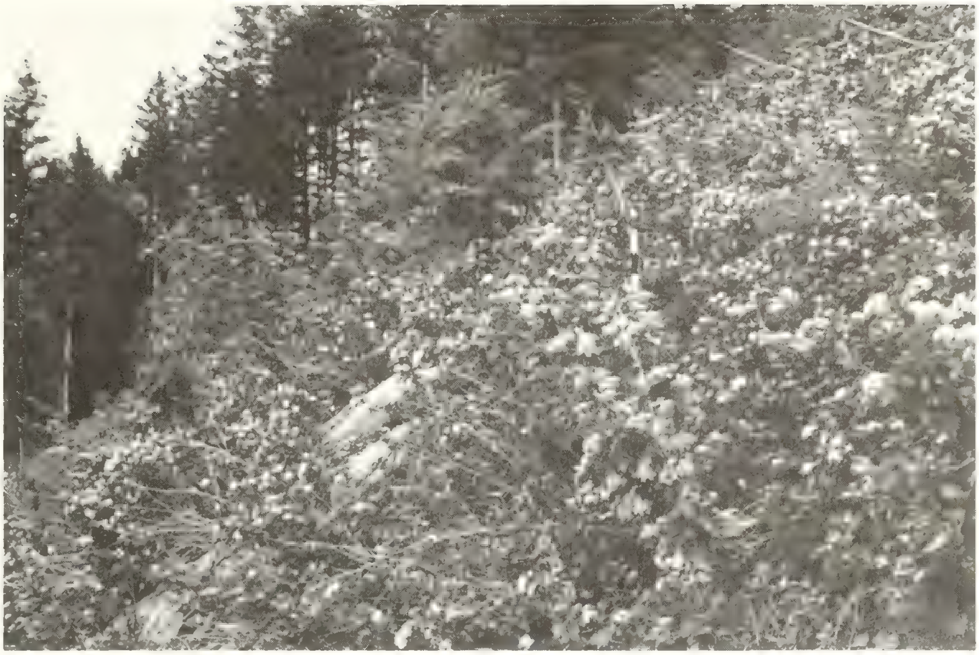

Figure 11—A PHMA-PHMA shrub layer type in Logging Gulch southeast of Idaho City, ID. This area was clearcut 10 years ago and given no site treatment. The shrub layer, mainly *Physocarpus*, existed prior to logging and has now developed a dense vigorous canopy as evidenced by the profuse flowering. Due to the dense shrub canopy, tree regeneration is now limited to the few *Pseudotsuga* saplings that survived the logging.

Acer and *Vaccinium* are treated as alternate successional indicators of *Physocarpus* in this habitat type.

Because the PHMA layer group represents climax conditions, only one layer type exists. The PHMA-PHMA layer type is the result of long-term succession and is not apt to be achieved through site manipulation. In most sampled stands the last disturbance was apparently wildfire about 48 to 160 years ago. Occasionally, climax stands that are clearcut with no site treatment remain in this shrub layer type. This creates an "unnatural" situation for conifer regeneration because there are no seral areas in which conifers may establish. Also, the increased sunlight allows *Physocarpus* to develop a vigorous canopy that can create too much competition for conifer seedlings (fig. 11).

MANAGEMENT IMPLICATIONS

The previous sections describe some layer groups that can be achieved through prescribed site treatments and others that result mainly from uninterrupted succession. The actual layer type that may result from a particular site treatment can often be projected on a stand-by-stand basis from species composition and known successional response. When land managers consider the possible shrub layer types that can result from alternative site treatments, they may also want to consider the relative forage value of these layer types for big game and livestock. Such values can be estimated from relative palatability ratings of plant species for elk (Kufeld 1973), deer (Kufeld and others 1973), cattle and sheep (USDA FS 1986), and black bear (Beecham 1981). The usual scale of 1 to 3 in these studies was expanded to 1 to 6 so as to emphasize the differences in palatability values. The relative palatability value for each plant species is listed in appendix B-1. This value was multiplied by the constancy (percentage occurrence in stands) and average canopy cover (appendix B) for that species in a given layer type. This step was repeated for all species in the layer type. The sum of all such products within a layer type resulted in a forage index value for that particular layer type. The index values were then reduced to classes in order to simplify forage value assessments and to eliminate the false impression of high precision between values (table 9).

These index classes reflect forage potential on a relative basis but do not necessarily reflect actual use, which is affected by juxtaposition of the surrounding vegetational types. Some index values may be biased by consistent disproportions of canopy cover to shrub volume. Likewise actual palatability within a species can vary with plant vigor; however, other sources of variation common to this type of comparison have been reduced. For instance, the possibility of species ecotypes having different palatabilities is reduced by restricting the data to one habitat type. Individual animals may have slightly different forage preferences, but all possible layer types can be made available to the same group of animals. Plant species palatabilities are listed by season to accommodate seasonal forage preferences. In spite of the shortcomings inherent with these kinds of comparisons, the forage index classes can provide general guidelines to relative browse potential for specific wildlife and range objectives

Table 9—Relative index classes to big-game and livestock forage preferences by shrub layer types in the PSME/PHMA h.t., PIPO phase[1]

Layer group	No. of	Deer		Elk		Cattle	Sheep	Black bear		
layer type	stands	SU[2]	W	SU	W	SU	SU	SP	SU	F
Ceanothus velutinus										
CEVE-CEVE	6	[3]6	4	6	6	2	3	0	0	0
CEVE-RICE	2	2	1	4	1	2	2	1	2	2
CEVE-SASC	10	7	3	4	6	3	4	0	1	1
CEVE-PREM	2	3	2	4	2	2	2	1	2	2
CEVE-AMAL	3	5	4	6	5	3	4	1	2	3
CEVE-SPBE	10	4	2	3	4	2	3	0	1	1
CEVE-PHMA	15	4	2	4	3	2	3	0	1	1
Ribes cereum										
RICE-RICE	2	1	1	2	1	1	2	1	2	1
RICE-AMAL	2	3	2	3	1	2	3	1	2	2
RICE-PHMA	1	2	1	3	1	1	2	0	1	1
Salix scouleriana										
SASC-SASC	3	4	1	2	3	2	3	0	1	1
SASC-AMAL	3	4	2	3	4	2	4	1	2	2
SASC-SPBE	4	5	2	3	3	2	3	1	1	1
SASC-PHMA	17	5	2	4	3	2	4	1	1	1
Prunus emarginata										
PREM-PREM	2	4	2	5	3	2	3	1	3	4
PREM-AMAL	1	4	3	4	2	2	3	1	2	2
PREM-SPBE	1	2	1	2	1	1	2	0	1	1
PREM-PHMA	8	4	2	4	2	2	3	1	1	2
Amelanchier alnifolia										
AMAL-SPBE	5	4	2	3	4	2	4	0	1	1
AMAL-PHMA	10	5	3	4	4	3	4	0	1	1
Spiraea betulifolia										
SPBE-SPBE	3	3	3	3	4	2	3	1	2	2
SPBE-PHMA	20	4	2	3	3	2	4	0	0	0
Physocarpus malvaceus										
PHMA-PHMA	21	3	2	3	2	2	3	0	0	0

[1] Based on palatability ratings by Kufeld (1973), Kufeld and others (1973), USDA FS (1986), and Beecham (1981).

[2] SP = spring (March, April, May); SU = summer (June, July, August); F = fall (September, October, November); W = winter (December, January, February).

[3] Code to index classes:

0 = 0-50;	1 = 51-150;	2 = 151-250 (low)
3 = 251-350;	4 = 351-450;	5 = 451-550 (moderate)
6 = 551-650;	7 = 651-750;	8 = 751-850 (high).

as well as multifunctional planning. Range and wildlife managers who may have better species palatability ratings for a local area can recalculate the forage indexes from appendix B, reduce the indexes to index classes (table 9), and apply the results to their area.

Forage index classes (table 9) vary according to kinds and amounts of plant species comprising the layer type. Because early seral layer types may contain more species than later stages, a greater data base may be needed to reflect the modal conditions and forage indexes. When the same layer type occurs in different habitat types or phases, species composition may increase with site potential, and more samples may be needed for the more productive sites. The index value, however, is most affected by coverages of the highly palatable species and does not necessarily increase with site productivity although this often is the case. Ranking of species' nutritional value between habitat types and seral stages could add refinement to the index values. Such considerations should be used when comparing relative significance of forage index classes.

Deer—Shrub layer forage values for deer herds in summer are mostly moderate (table 9). Some exceptions are high values in the CEVE-CEVE and CEVE-SASC layer types (caused by intense burning) and low values in CEVE-RICE, RICE-RICE, and RICE-PHMA layer types (caused by scarification). In winter, forage values are low to moderate throughout PSME/PHMA succession. The highest values occur in the CEVE-CEVE and CEVE-

AMAL layer types. CEVE-CEVE can be created by intense broadcast burning, whereas CEVE-AMAL is most likely to occur by burning other shrub layer types having a high frequency of *Amelanchier*.

Elk—Summer forage values for elk are mostly moderate but are high in the CEVE-CEVE and CEVE-AMAL layer types (table 9). These two layer types also had the highest value for deer in winter. Forage values for elk in winter are mostly low to moderate but rank high in the CEVE-CEVE and CEVE-SASC layer types. Both of these layer types result from clearcutting followed by intense burning.

Cattle—Shrub layer forage values for cattle are low in most seral stages of PSME/PHMA. Moderate forage values occur only in the CEVE-SASC, CEVE-AMAL, and AMAL-PHMA layer types. The occurrence of *Amelanchier* in these layer types, as opposed to its alternate indicator, *Symphoricarpos oreophilus*, appears to be the main forage species.

Sheep—Forage values for sheep are generally moderate throughout PSME/PHMA succession (table 9). Only the CEVE-RICE, CEVE-PREM, RICE-RICE, and RICE-PHMA layer types ranked low. Most shrub layer types rank higher for sheep than for cattle. Several layer types in the CEVE and PREM layer groups rank higher for deer or elk than for sheep.

Black Bear—There is only low food value for black bear in most stages of PSME/PHMA succession (table 9). Two exceptions are the CEVE-AMAL and PREM-PREM layer types, which ranked moderate due to high coverages of *Amelanchier* and/or *Prunus*. These two species also occur in other shrub layer types but did not have adequate canopy cover to rank high or moderate in bear forage value. The late summer to early fall fruit crops of these two shrub species provide the increased forage.

Planted Tree Seedlings and Shrub Competition—Potential competition of shrubs with tree seedlings is a function of existing vegetation, seed availability, site treatment, and habitat type or phase. The habitat type or phase classifies the environment, which in turn determines which species can occur on the site and the magnitude of their potential roles. For instance, *Acer* and *Physocarpus* can produce a major shrub layer in PSME/PHMA but are of little or no importance in the drier Douglas-fir habitat types. Predicting what species might occur or dominate by simply inspecting a site prior to disturbance is not always possible. Old-growth stands may contain a multitude of early seral species in the form of buried seed (Kramer 1984); other species establish by windblown seed. Table 10 shows which shrubs in PSME/PHMA store seed in the soil and important methods of seed dissemination, vegetative increase, and germination response to site treatment. Potential shrub competition for a given site is best estimated by noting kinds and amounts of existing shrubs on that site, the other species that may occur (table 7), and reactions of all species to the site treatment planned (table 10). This set of interacting variables is complex but provides an ecological basis for site-specific prescribed treatments. In contrast, generalized descriptions of site treatment and potential shrub responses tend to represent an average stand condition. Such predictions can be misleading for site-specific management because few stands would match the average condition.

The following paragraph describes how components of tables 7 and 10 and figure 6 can be assembled to meet site-specific conditions. Considerations for each stand may differ but should include:

1. The desired tree species, its shade tolerance and growth rate;
2. Kind and intensity of site treatment in terms of reducing existing competition;
3. Existing shrub species and their potential for reacting to the proposed timber harvest and to the site treatment selected;
4. Potential reactions of buried seed and windblown seed to the site treatment selected; and
5. Duration of the potential competition in terms of height-age interactions of shrub species and tree seedlings.

Duration of competition for tree seedlings depends on height-age interactions with the shrubs. For instance, *Pinus ponderosa* seedlings may become overtopped by *Ribes* seedlings from years 2 to 7 (fig. 12). The *Ribes* canopy, however, is usually sparse and should not seriously jeopardize pine survival. If free from suppression, properly planted *Pinus ponderosa* can outgrow most shrubs germinating from seed at the time of planting, but if the pines are planted after the first growing season following the disturbance, shrubs germinating from seed may seriously outcompete the pine (figs. 13a, b). Nevertheless, even pines planted the first growing season may not outcompete shrubs growing from sprouts. For example, *Pinus ponderosa* seedlings may overtop *Amelanchier* sprouts in about 10 years but are likely to be outcompeted by *Salix* sprouts (fig. 12). The pine's growth rate, however, is also affected by shrub density, which can be regulated by the kind and intensity of site disturbance (table 10). For instance, clearcutting can result in major canopy increases of *Salix* and *Prunus* that are already present on the site. Clearcutting followed by mechanical scarification can generate large amounts of *Ribes* from buried seed but only minor amounts of other shrub seedlings (table 10). When selecting a treatment to minimize certain shrub species, one must also guard against the possibility of greatly increasing some other species. For instance broadcast burning results in minor amounts of most shrubs from seed but generates major amounts of *Ceanothus*. Consequently the optimum treatment for any given site depends on the existing shrub layer as well as the potential for shrub seedlings.

Natural Tree Establishment—Naturally established tree seedlings were recorded by species, silvicultural treatment, and microsite conditions. A seedling was defined as a tree less than 4.5 feet (1.4 m) tall and 3 years old or older, but younger than the disturbance.

A total of 337 natural *Pinus ponderosa* and *Pseudotsuga menziesii* seedlings per acre were recorded in the PSME/PHMA h.t., PIPO phase. Most of these (82 percent) were

Table 10—Responses of major shrub species to various disturbances in the PSME/PHMA h.t., PIPO phase

Species	Seed transport; reproduction methods	Maximum heights	Type of disturbance				
			CC, NP	SC, MS	CC, MS	CC, BB	WF
		Feet					
PHMA	No obvious transport; seed stored in soil (11% viable).[1] Germinates in partial shade on scarified soil. Increases by root sprouts.	3 - 5	V	V-s	V	V	V
ACGL	Wind; not stored in soil. Germinates in partial shade on scarified soil. Stumps resprout.	10 - 15	V	V-s	V	V	V
VAGL	Birds, mammals; stored in soil (23% viable). Germinates in partial shade on moist soil. Increases by shallow rhizomes.	2 - 2^{1}/2	v	V-s	v	v	v
RUPA	Birds, mammals; stored in soil (14% viable). Increases by rhizomes.	2 - 3	V	V	V	V	V
SYAL	Birds, mammals; not stored in soil. Increases by rhizomes.	1 - 2^{1}/2	V	v	V	V	V
SPBE	No obvious transport; not stored in soil. Increases by rhizomes.	1 - 1^{1}/2	V	v	V	V	V
AMAL	Birds, mammals; not stored in soil. Germinates on bare soil in partial shade. Stumps resprout.	6 - 8	v	v-s	v-s	v-s	v-s
SYOR	Birds, mammals; not stored in soil. Germinates on bare soil in partial shade. Stumps resprout.	2 - 3	v	v-s	v-s	v-s	v-s
PREM and PRVI	Birds, mammals; stored in soil (27% viable). Germinates in full sun following scarification or burning. Increases by root sprouts.	7 - 12	V	v	V-s	V-s	V-s
SASC	Wind; not stored in soil. Germinates on moist mineral soil in full sun. Stumps resprout.	15 - 25	V	v	V-s	V-s	V-s
PHLE	No obvous transport; storage capability unknown. Germinates in full sun. Stumps resprout.	4 - 8	v	v	v-s	v-s	v-s
RICE and RIVI	Birds, mammals; stored in soil (96% viable). Germinates on mineral soil in full sun.	3 - 5	v	v-s	v-S	s	s
CEVE and CESA	No obvious transport; stored in soil (91% viable). Germinates mainly from burning and partially from scarification in full sun.	4 - 6	v	v	v-s	S	S

DISTURBANCE CODES:

CC, NP = Clearcut, no site preparation
SC, MS = Shelterwood cut, mechanical scarification
CC, MS = Clearcut, mechanical scarification
CC, BB = Clearcut, broadcast burned
WF = Stand-destroying wildfire

RESPONSE CODES:

V = Major vegetative response (coverage increases from existing plants and vigorous sprouting following tree removal but is offset by treatment intensity).
v = Minor vegetative response (coverage increases either from just the existing plants following tree removal or from existing plants and nonvigorous sprouting but is offset by treatment intensity.
S = Major response from seed (coverage increase depends on amount of viable seed available and is enhanced by treatment intensity).
s = Minor response from seed (same criteria as for S).

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[1] Stored seed viabilities are from Kramer (1984).

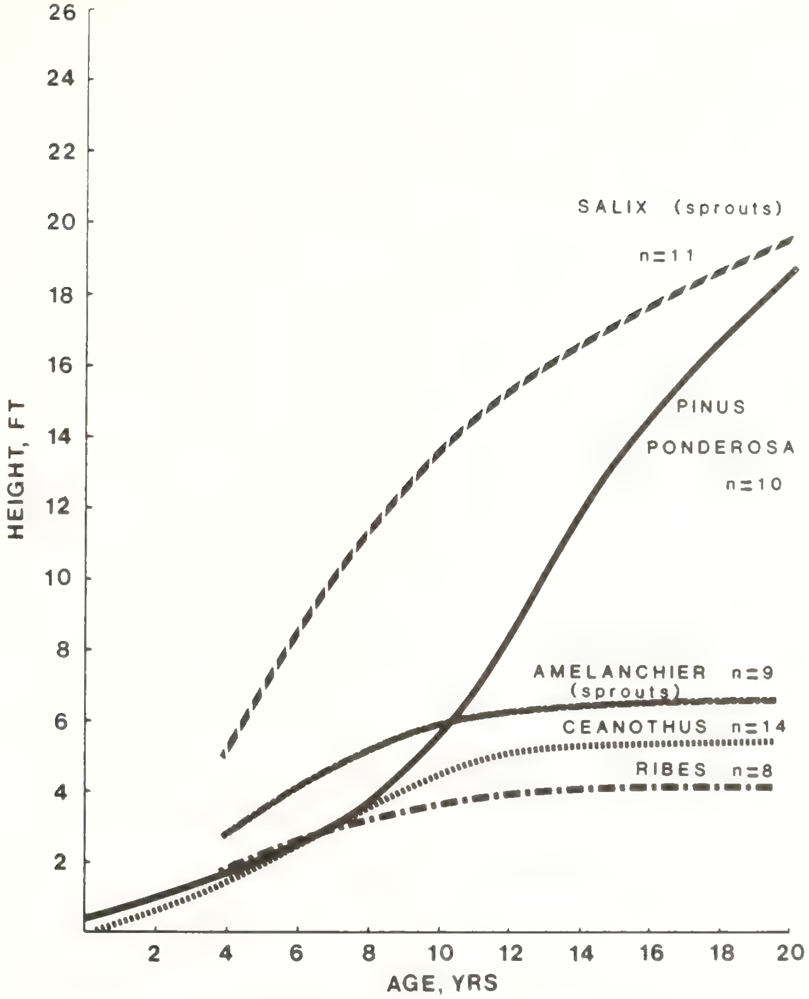

Figure 12—Height-age relationships of planted free-growing PIPO seedlings and important free-growing shrub species in the PSME/PHMA h.t., PIPO phase.

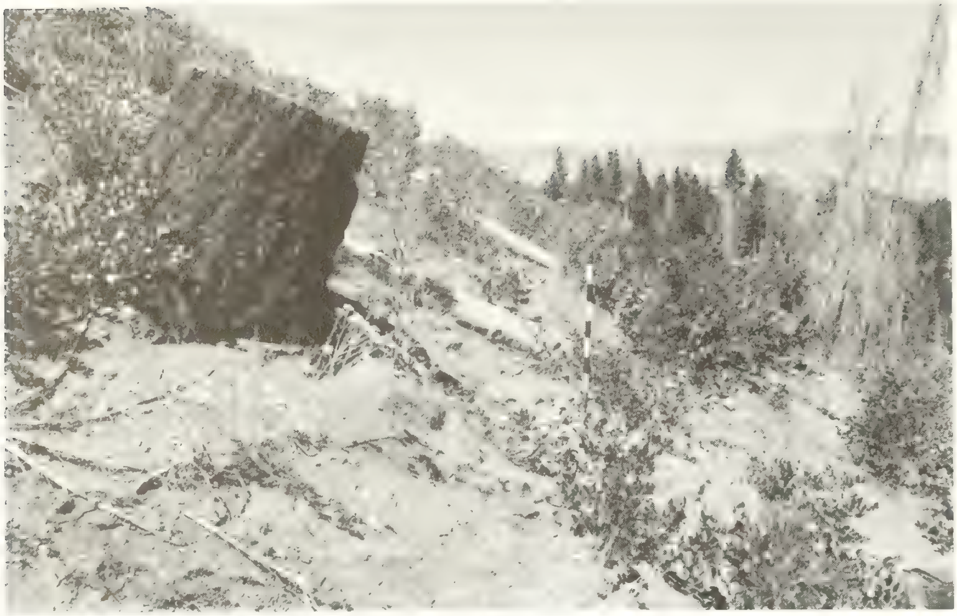

Figure 13a—A site that was clearcut and broadcast burned 4 years ago in 1975. This site was planted to ponderosa pine the spring following burning, but survival was poor. It was replanted in the fall 2 years later (in 1978). A shrub layer of *Ceanothus* from buried seed and *Physocarpus* from sprouts is now in its fourth growing season.

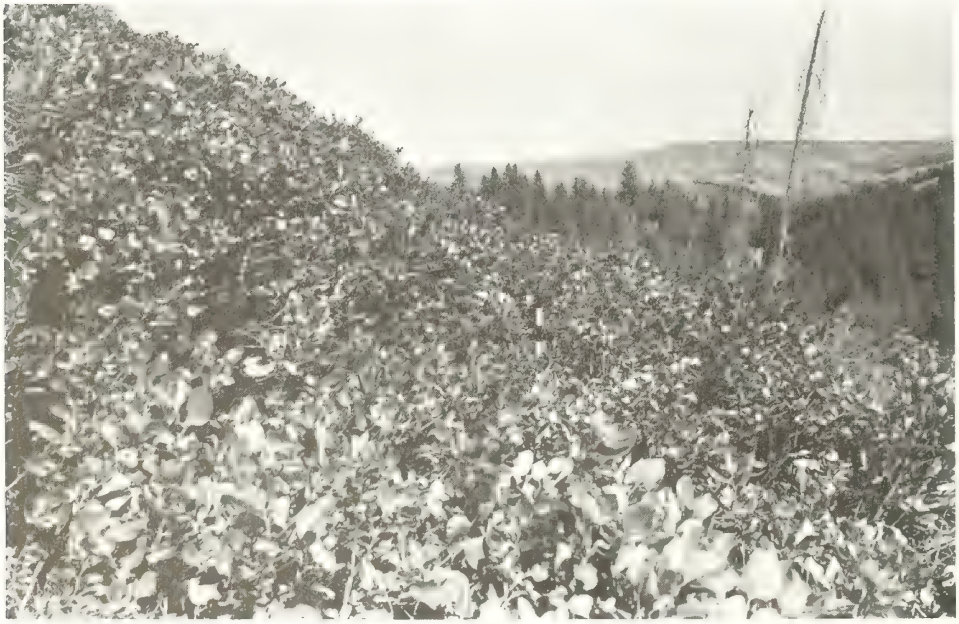

Figure 13b—Same site as above in 1986, 11 years after broadcast burning. The pine seedlings from the second planting still persist but are now seriously overtopped by the shrub layer, which has a three-growing-season lead. Pine seedlings from the first planting are scarce but are now safely above the shrub layer.

Pseudotsuga. For each seedling in each microsite, a regeneration efficiency (RE) value was computed. An RE value of 1.00 indicates that the seedlings occurred on a particular microsite in proportion to the occurrence of the microsite. Values greater than 3.01 are designated very efficient, 1.51 to 3.00 moderately efficient, 0.76 to 1.50 efficient, 0.26 to 0.76 inefficient, and less than 0.25 very inefficient. RE values were calculated for each microsite component (seedbed or cover).

Although RE values may reflect a relationship between the microsite and tree seedling, several factors affect interpretation of these values. It was assumed that seedlings persist only in favorable microsites; if a seed germinates in a favorable microsite which then deteriorates, such as through rapid shrub development, the seedling could die. Some seedlings may have been recorded in unfavorable microsites, but are still living. Therefore, some microsites identified as beneficial may in fact preclude development of tree seedlings. In this respect, the microsite canopy cover is more influential than the seedbed through time. The relationship between the microsite canopy cover and seedling was not always easy to determine. In some cases, the tree seedling and canopy cover may have benefited from the same microsite and simply established near one another coincidentally. In other cases, the tree seedling may have benefited from the existing cover, which provided more favorable microsite conditions in terms of shade, soil moisture and nutrients, humidity, temperature, and wind protection (Zavitkovski and Woodard 1970). Some microsites with cover vegetation may favor one seedling species but not another. A heavy canopy cover may favor shade-tolerant tree species but not shade-intolerant species, or an allelopathic cover species may deter establishment of some tree seedlings and not others. Where a positive seedling-microsite relationship exists, the canopy cover species may be used to help establish natural regeneration, or to indicate favorable microsites. Where a negative relationship exists, canopy cover species may indicate unfavorable microsites.

Pinus ponderosa regeneration is highest in group selection cuts (table 11). For silvicultural treatments (other than clearcuts) supporting *P. ponderosa* seedlings, the average distance to a *P. ponderosa* seed source was 25 feet (8 m). Treatments with no seedlings had an average distance to seed source of 91 feet (28 m). *Pinus ponderosa* seedling occurrence was only 2 percent in clearcuts, and the average distance to a seed source was 182 feet (55 m).

Most *P. ponderosa* seedlings (77 percent) occurred following light scarification due to logging activities or slash disposal (table 12). No seedlings were found on heavy scarification from contour terracing. Most seedlings occurred on bare mineral soil, which is a moderately efficient seedbed (table 13). No seedlings were found under heavy (67 to 100 percent) canopy cover, though the majority were under moderate (34 to 66 percent) canopy cover (table 14). *Symphoricarpos* and *Amelanchier* are very efficient covers for *P. ponderosa* seedlings; *Physocarpus* and *Ribes* are moderately efficient (table 15). Slash and *Ceanothus velutinus* are inefficient. Most seedlings (51 percent) established in areas without a tree layer (table 16). In terms of shrub layer, most seedlings (83 percent) were found in the SASC layer group but not under the *Salix* (table 16).

On some sites, seed caches may play an important role in *P. ponderosa* establishment. In the Oregon Cascade Range, West (1968) found that 15 percent of the *P. ponderosa* seedlings resulted from rodent caches. In central Idaho, McConkie and Mowat (1936) reported 14 percent rodent-cached *P. ponderosa*. Medin (1984) indicated that the yellowpine chipmunk (*Eutamias amoenus*) may be responsible for many of the caches found in central Idaho, though Clark's nutcracker (*Nucifraga columbiana*) may also be involved (Lanner 1980). In the *Pseudotsuga menziesii/Carex geyeri* h.t., *Pinus ponderosa* phase, 22 percent of the *P. ponderosa* regeneration apparently established from seed caches (Steele and Geier-Hayes 1987a). The occurrence was similar in the *Pseudotsuga menziesii/Spiraea betulifolia* h.t. (16 percent) and *Abies grandis/Vaccinium globulare* and *Abies grandis/Acer glabrum* h.t.'s (both 17 percent) (Geier-Hayes 1987). But none of the *Pinus ponderosa* seedlings sampled in the PSME/PHMA h.t. apparently resulted from seed caches.

Group selection cuts, seed-tree cuts, or small 1- to $1^1/_2$-acre (0.4- to 0.6-ha) clearcuts are probably the most effective treatment for establishment of *P. ponderosa* natural regeneration. Even though few natural seedlings were found on sampled clearcuts, many of these cuts were too large to provide adequate seed dispersal to the site. The average distance to a seed source for sampled clearcuts was 182 feet (55 m) (table 11) and researchers in central Idaho have found that most (82 percent) of the *P. ponderosa* seed falls within 100 feet (30 m) of the seed source (USDA FS 1940). Our survey substantiates this; all the *P. ponderosa* seedlings were found in cutting units where the average distance to a seed source was less than 100 feet (30 m) (table 11). Small strip clearcuts of 200 to 250 feet (61 to 76 m) wide (Foiles and Curtis 1973) or patch clearcuts should regenerate well if adequate seed sources are nearby. In all cases, 50 to 60 percent of the area should be scarified to remove the duff and expose mineral soil. Effective scarification treatments are those that produce the RICE or SASC layer group. Regeneration may also be adequate in scarified areas with high coverages of *Symphoricarpos* or *Amelanchier alnifolia* because both species are very effective covers for *P. ponderosa* seedlings.

Pseudotsuga menziesii regeneration is highest in group selection cuts (36 percent) and lowest in clearcuts (17 percent) (table 11). In cutting units with *Pseudotsuga* seedlings, the average distance to a seed source was 122 feet (37 m). For sites with no seedlings, the average distance to a *Pseudotsuga* seed source was 145 feet (44 m). Although many seedlings (31 percent) were found on unprepared sites (table 12), no seedlings were found on residual duff (table 13). Scarification treatments and broadcast burning are only slightly less effective than no site preparation. Moss mats are very efficient seedbeds for *Pseudotsuga* seedlings, and most moss mats were found on scarified soils. Litter-covered mineral soil and bare mineral soil were efficient and inefficient, respectively.

Table 11—Occurence of natural tree seedlings (percent) by silvicultural method and percent overstory composition for the PSME/PHMA h.t., PIPO phase

Silvicultural method	Number of sites sampled[1]	Overstory cover[2]	Distance to seed source[3]	Seedling occurrence	
				PIPO	PSME
		Percent	*Feet*	---- *Percent* ----	
CLEARCUT	15			2	17
Overstory					
Pinus ponderosa		0	182		
Pseudotsuga menziesii		0	136		
SEED-TREE CUT	3			15	20
Overstory				Breakdown of seedling occurrence by overstory composition	
Pinus ponderosa	2	8	33	100	100
Pseudotsuga menziesii		0	200		
Pinus ponderosa	1	1	150	-	-
Pseudotsuga menziesii		10	175		
SHELTERWOOD CUT	1			0	0
Overstory					
Pinus ponderosa	1	3	100		
Pseudotsuga menziesii		3	50		
SELECTION CUT	4			75	37
Overstory				Breakdown of seedling occurrence by overstory composition	
Pinus ponderosa	3	12	42	100	50
Pseudotsuga menziesii		1	87		
Pseudotsuga menziesii	1	15	[4]0	-	50
STAND-DESTROYING WILDFIRE	3			8	26
Overstory				Breakdown of seedling occurrence by overstory composition	
Pinus ponderosa	1	0	200	-	15
Pseudotsuga menziesii		0	150		
Pinus ponderosa		3	0	100	77
Pseudotsuga menziesii		3	0		
Pinus ponderosa		0	70	-	8
Pseudotsuga menziesii		3	0		

[1] Each site contained five sampled microplots.
[2] Percent canopy cover of trees >4 inches d.b.h.
[3] Distance from center of 375-m^2 plot to seed source; immature trees often comprised overstory composition.
[4] Seed source on plot.

Table 12—Occurrence of natural tree seedlings (percent) by site preparation method for the PSME/PHMA h.t., PIPO phase

Species	Site preparation				
	None	Broadcast burn	Wildfire	Scarification Light	Scarification Heavy
	---------------- *Percent* ----------------				
Pinus ponderosa	0	13	10	77	0
Pseudotsuga menziesii	31	23	18	12	16
	---------------- *Number* ----------------				
Sites[1]	3	7	4	8	4

[1] Each site contained five sampled microplots.

Table 13—Occurrence of natural tree seedlings (percent) by seedbed with regeneration efficiencies (RE)[1] of seedbeds for the PSME/PHMA h.t., PIPO phase

Species	Seedbed: Litter-covered scarified		Bare mineral soil		Moss mat		Rotten wood		Residual duff		Rocks or stumps	
	Pct	*RE*	*Pct*	*RE*	*Pct*	*RE*	*Pct*	*RE*	*Pct*	*RE*	*Pct*	*RE*
Pinus ponderosa	39	0.75	61	1.62	—	—	—	—	—	—	—	—
Pseudotsuga menziesii	43	1.09	10	.34	47	4.70	—	—	—	—	—	—
Seedbed occurrence[2]	55		36		6		1		1		1	

[1]Regeneration efficiency is the percent occurrence of each seedling species divided by the percent area occupied by the seedbed.
[2]Percent occurrence of seedbed in all microplots.

Table 14—Occurrence of natural tree seedlings (percent) by shrub canopy cover for the PSME/PHMA h.t., PIPO phase

Species	Shrub canopy cover: Light (0-33%)	Moderate (33-66%)	Heavy (66-100%)
	Percent		
Pinus ponderosa	34	66	0
Pseudotsuga menziesii	23	58	19
	Number		
Microplots	48	35	32

Table 15—Regeneration efficiency (RE)[1] values of shrub canopies and other microsites for tree seedlings in the PSME/PHMA h.t., PIPO phase

Canopy	Canopy constancy	Area occupied	*Pinus ponderosa*	*Pseudotsuga menziesii*
	Percent		*RE*	*RE*
None[2]	-	-	-	-
Forbs	98	21		0.27
Ceanothus velutinus	45	14	0.42	1.85
Grasses and sedges	86	11		.40
Physocarpus malvaceus	69	11	1.64	2.42
Slash	72	10	.60	.70
Spiraea betulifolia	66	8		1.33
Pinus ponderosa	31	5	1.29	.50
Prunus spp.	34	4		
Salix scouleriana	15	3		1.36
Symphoricarpos spp.	39	3	3.96	
Rosa spp.	21	3		
Amelanchier alnifolia	23	2	6.09	1.77
Ribes spp.	15	2	2.68	.52
Berberis repens	22	1		
Sorbus scopulina	4	1		
Sambucus spp.	9	1		
Populus tremuloides	7	1		
Vaccinium globulare	1	<1		
Lonicera utahensis	4	<1		
Pseudotsuga menziesii	2	<1		
Acer glabrum	4	<1		
Chrysothamnus nauseosus	2	<1		
Rubus parviflorus	1	<1		

[1]Regeneration efficiency is the percent occurrence of the seedling species divided by the percent area occupied by the cover. No entry indicates that no seedlings were found.

[2]During sampling, no estimate of "none" type of cover was made for each plot; therefore, no RE value could be calculated. However, 35 percent of the *Pinus ponderosa* and 9 percent of the *Pseudotsuga menziesii* seedlings were found under no cover.

Table 16—Occurrence of natural tree seedlings (percent) by tree and shrub layer groups in the PSME/PHMA h.t., PIPO phase

Layer group	Number of sites[1]	Seedling species PIPO	PSME
		- - - - - *Percent* - - - - -	
TREE LAYER GROUPS			
depauperate	16	51	20
POTR	2	29	6
PIPO	6	20	20
PSME	2	-	54
SHRUB LAYER GROUPS			
depauperate	2	-	2
CEVE	11	1	12
RICE	2	13	26
SASC	2	83	28
PREM	5	3	5
AMAL	1	-	19
SPBE	1	-	-
PHMA	2	-	8

[1] Each site contained five sampled microplots.

Many of the *Pseudotsuga* seedlings (58 percent) were found in moderate shade (table 14). *Ceanothus* spp., *Amelanchier*, and *Physocarpus* were moderately efficient covers (table 15). Slash, *Ribes* spp., forbs, and grasses and sedges were inefficient. *Salix* and *Spiraea* were both efficient.

In terms of tree layer groups, most seedlings (54 percent) were found in the PSME layer group (table 16). In the shrub layers, many *Pseudotsuga* seedlings (28 percent) were found in the SASC layer group, followed by the RICE layer group (26 percent). Depauperate shrub layers resulted in the fewest seedlings (2 percent).

Small group selection cuts or small strip or patch clearcuts that have been scarified to produce the SASC or RICE layer groups or burned to produce the CEVE layer group should regenerate natural *Pseudotsuga* in the PSME/PHMA h.t. In the RICE layer group, however, continuous cover of *Ribes* may preclude *Pseudotsuga* establishment because *Ribes* is an inefficient cover for *Pseudotsuga*. In this case, layer types other than RICE-RICE, such as RICE-AMAL or RICE-PHMA, should regenerate well because both *Amelanchier alnifolia* and *Physocarpus* are moderately efficient covers for *Pseudotsuga*.

The Herb Layer

The herb layer is the most complex and least understood of the three vegetation layers. Modal conditions of seral stages are evident but more variable because there are more species. More species imply potentially more herb layer types, but the relative increase has been less than expected. It is possible that more kinds of disturbance are needed to generate the potentially broad array of layer types. Still, the following herb layer classification appears to follow logical successional sequences even though it may eventually need more refinement than the tree or shrub layer classification.

Table 17 lists the major herb layer species, which were those that showed greater than 5 percent cover somewhere in the data. Many unlisted species may be present in lesser amounts, and some potentially important species may yet be found. Relative successional amplitudes were

Table 17—Successional roles of major herb layer species in the PSME/PHMA h.t., PIPO phase

ADP No.	Herb layer species	Abbreviation	Role[1]
	Perennial graminoids		
303	*Bromus carinatus*	BRCA	(ES)
282	*Bromus inermis*	BRIN	ES
317	*Calamagrostis rubescens*	CARU	(C)
309	*Carex geyeri*	CAGE	LS
331	*Poa nervosa*	PONE	LS
	Perennial herbs		
566	*Agastache urticifolia*	AGUR	(ES)
415	*Apocynum androsaemifolium*	APAN	MS
413	*Antennaria racemosa*	ANRA	(LS)
420	*Arenaria macrophylla*	ARMA	LS
421	*Arnica cordifolia*	ARCO	C
426	*Aster conspicuus*	ASCO	LS
431	*Balsamorhiza sagittata*	BASA	(ES)
438	*Castilleja miniata*	CAMI	MS
459	*Epilobium angustifolium*	EPAN	(MS)
465	*Fragaria vesca*	FRVE	MS
466	*Fragaria virginiana*	FRVI	(MS)
471	*Galium triflorum*	GATR	LS
473	*Geranium viscosissimum*	GEVI	ES
833	*Iliamna rivularis*	ILRI	ES
636	*Lathyrus nevadensis*	LANE	(C)
658	*Penstemon attenuatus*	PEAT	(MS)
514	*Penstemon wilcoxii*	PEWI	LS
522	*Potentilla glandulosa*	POGL	ES
675	*Rudbeckia occidentalis*	RUOC	ES
547	*Thalictrum occidentale*	THOC	(C)
691	*Veratrum californicum*	VECA	MS

[1]ES = Early seral
MS = Mid-seral
LS = Late seral to climax
C = Climax
( ) = Occurs in only part of the PIPO phase

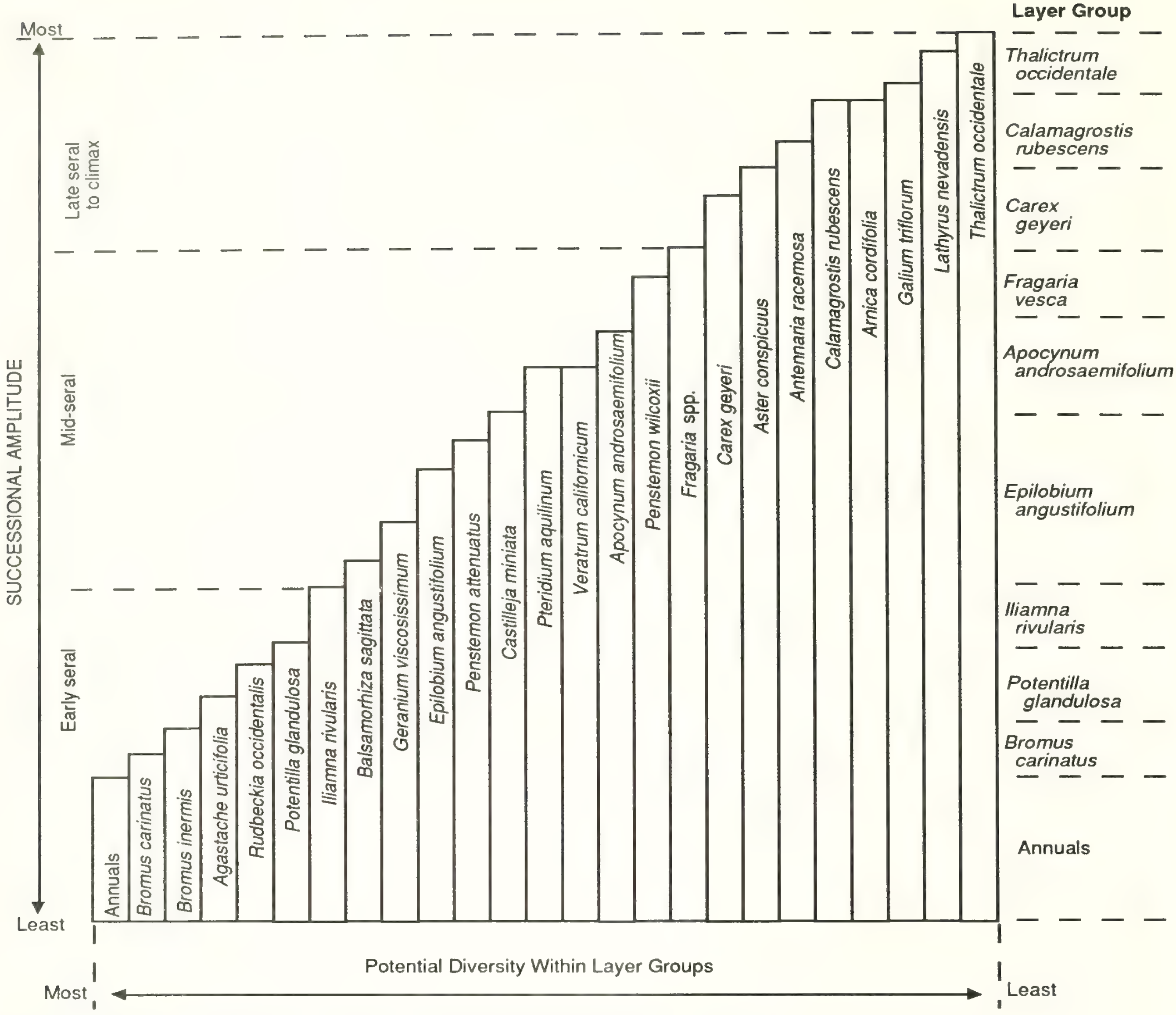

Figure 14—Relative successional amplitudes of important herb layer species in the PSME/PHMA h.t., PIPO phase.

derived for important herb layer species (fig. 14). This was accomplished by developing hypotheses for each species, then by testing each hypothesis through field observation and data analysis. Because succession in the herb layer progresses more rapidly than the tree or shrub layer, successional amplitudes for some herb layer species can also be derived from the permanent plot records of Stickney (1980, 1985). As in the tree and shrub layer, successional amplitudes of herb layer species are meaningful only in a relative sense, and the greatest accuracy lies with those amplitudes that are farthest apart. For instance, species indicating the Annuals layer group clearly have less amplitude than *Thalictrum* (fig. 14). But there is less certainty to the relative amplitudes of adjacent species such as *Fragaria* versus *Carex geyeri*.

The relative successional amplitudes in figure 14 provide a basis for the present herb layer classification (fig. 15). This classification consists of 10 layer groups; the full data set appears in appendix C. Although the classification is based on 100 sample plots, some layer groups have little data. The Annuals layer group are weakly represented because these species often occur within 5 years following disturbance and such sites were not heavily sampled. Other layer types may be found with more reconnaissance, may appear only after uncommon disturbances, or may be rare under any circumstance.

The key to herb layer types (table 18) contains numerous alternate indicator species. Much of this lumping is necessary to maintain a workable number of units in this diverse vegetative layer. In some cases, combining

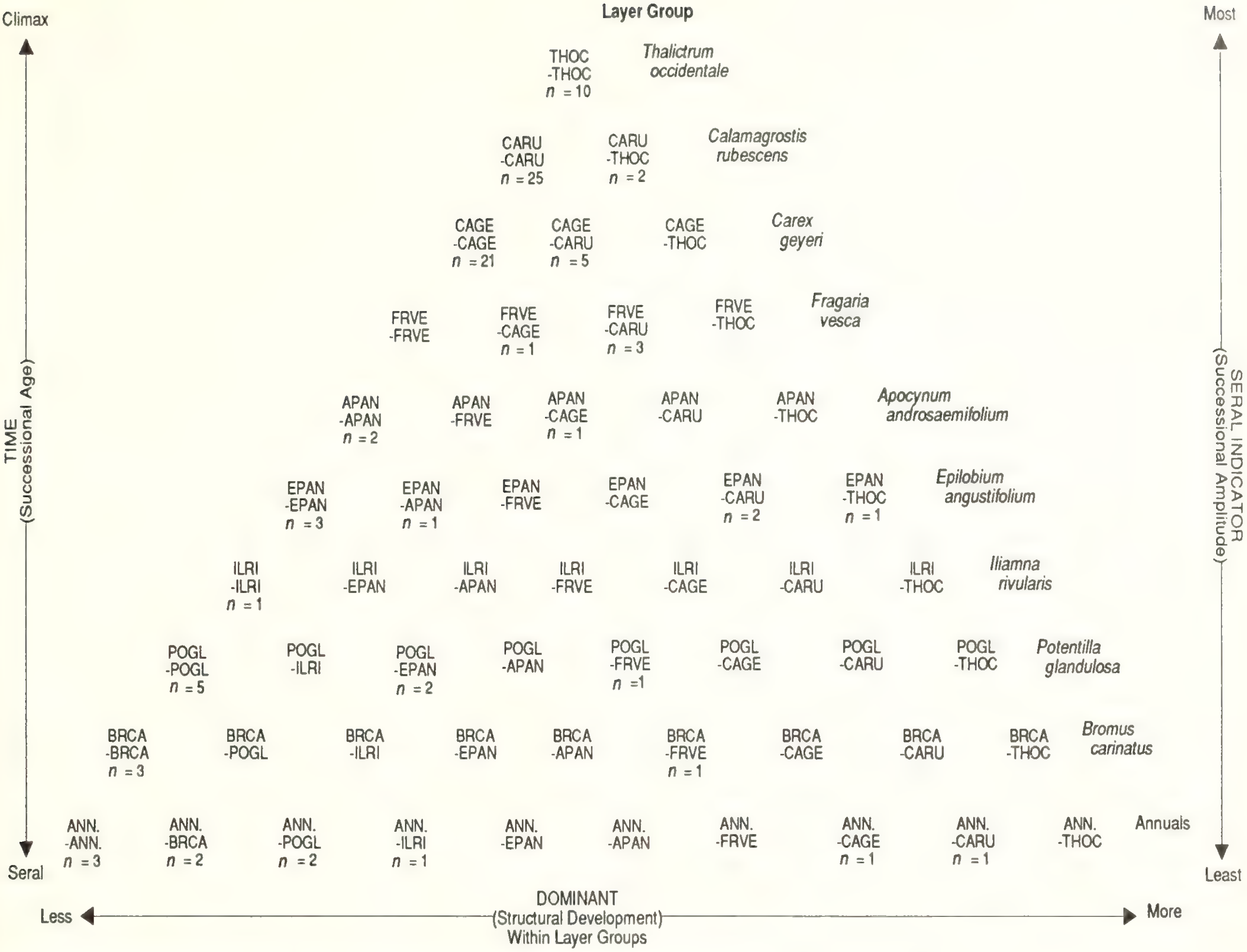

Figure 15—Succession classification diagram of the herbaceous layer in the PSME/PHMA h.t., PIPO phase (n = number of samples in each layer type).

indicator species has reduced uniformity within the unit because the species represent minor differences of environment or successional pattern within the habitat type. In other cases, the alternate indicators are common environmental and successional equivalents, and the classified unit retains substantial uniformity. In all cases the lumped species appear to have similar successional amplitudes (fig. 14).

Early seral annuals, biennials, and short-lived perennials were grouped into one unit because there appears to be no practical reason to recognize them individually. *Rudbeckia* and *Agastache* were grouped with *Potentilla* because of similar responses to scarificartion. *Balsamorhiza, Geranium,* and *Penstemon attenuatus* were occasionally well represented near the dry extreme of PSME/PHMA and were grouped with *Epilobium* as indicators of mid-seral conditions. *Castilleja* from the moist extremes of the habitat type was also grouped with *Epilobium* for this reason. *Pteridium* and *Veratrum* were each well represented in only one sample plot and were subjectively grouped with *Apocynum* as mid-seral indicators. *Carex geyeri* and *Aster conspicuus* were combined as late seral indicators; *Arnica cordifolia, Antennaria racemosa,* and *Galium triflorum* were grouped with *Calamagrostis rubescens* as near-climax indicators. *Lathyrus nevadensis* was grouped with *Thalictrum* as a climax associate.

Table 18—Key to herb layer groups and layer types, with ADP codes, in the PSME/PHMA h.t., PIPO phase

			ADP codes
1.	Annuals, biennials, and short-lived perennials (see layer group description for species) well represented (≥5%)[1] either individually or collectively (Choose first condition that fits)	ANNUALS Layer Group	900
1a.	The above species dominant[2]	ANN.-ANN. Layer Type	900.900
1b.	*Bromus carinatus* (incl. *Bromus inermis* and *Agropyron intermedium*) dominant or codominant[3]	ANN.-BRCA Layer Type	900.303
1c.	*Potentilla glandulosa* (incl. *Agastache* and *Rudbeckia*) dominant or codominant	ANN.-POGL Layer Type	900.522
1d.	*Iliamna* dominant or codominant	ANN.-ILRI Layer Type	900.833
1e.	*Epilobium angustifolium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) dominant or codominant	ANN.-EPAN Layer Type	900.459
1f.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) dominant or codominant	ANN.-APAN Layer Type	900.415
1g.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) dominant or codominant	ANN.-FRVE Layer Type	900.465
1h.	*Carex geyeri* (incl. *Aster conspicuus)* dominant or codominant	ANN.-CAGE Layer Type	900.309
1i.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	ANN.-CARU Layer Type	900.307
1j.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	ANN.-THOC Layer Type	900.547
1.	Annuals, biennials, and short-lived perennials poorly represented (<5%)	2	
2.	*Bromus carinatus* (incl. *Bromus inermis* and *Agropyron intermedium*) well represented (≥5%) (Choose first condition that fits)	BRCA Layer Group	303
2a.	The above species dominant	BRCA-BRCA Layer Type	303.303
2b.	*Potentilla glandulosa* (incl. *Agastache* and *Rudbeckia*) dominant or codominant	BRCA-POGL Layer Type	303.522
2c.	*Iliamna* dominant or codominant	BRCA-ILRI Layer Type	303.833
2d.	*Epilobium angustifolium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) dominant or codominant	BRCA-EPAN Layer Type	303.459
2e.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) dominant or codominant	BRCA-APAN Layer Type	303.415
2f.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) dominant or codominant	BRCA-FRVE Layer Type	303.465
2g.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	BRCA-CAGE Layer Type	303.309
2h.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	BRCA-CARU Layer Type	303.307
2i.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	BRCA-THOC Layer Type	303.547
2.	*Bromus* spp. poorly represented (<5%)	3	
3.	*Potentilla glandulosa* (incl. *Agastache* and *Rudbeckia*) well represented (≥5%) (Choose first condition that fits)	POGL Layer Group	522
3a.	The above species dominant	POGL-POGL Layer Type	522.522
3b.	*Iliamna* dominant or codominant	POGL-ILRI Layer Type	522.833
3c.	*Epilobium angustifolium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) dominant and codominant	POGL-EPAN Layer Type	522.459
3d.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) dominant or codominant	POGL-APAN Layer Type	522.415
3e.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) dominant or codominant	POGL-FRVE Layer Type	522.465
3f.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	POGL-CAGE Layer Type	522.309
3g.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	POGL-CARU Layer Type	522.307
3h.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	POGL-THOC Layer Type	522.547
3.	*Potentilla* (incl. *Agastache* and *Rudbeckia*) poorly represented (<5%)	4	
4.	*Iliamna rivularis* well represented (≥5%) (Choose first condition that fits)	ILRI Layer Group	833
4a.	*Iliamna* dominant	ILRI-ILRI Layer Type	833.833
4b.	*Epilobium angustifolium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) dominant or codominant	ILRI-EPAN Layer Type	833.459
4c.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) dominant or codominant	ILRI-APAN Layer Type	833.415
4d.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) dominant or codominant	ILRI-FRVE Layer Type	833.465

(con.)

			ADP codes
4e.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	ILRI-CAGE Layer Type	833.309
4f.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	ILRI-CARU Layer Type	833.307
4g.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	ILRI-THOC Layer Type	833.547
4.	*Iliamna* poorly represented (<5%)	5	
5.	*Epilobium angustifolium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) well represented (≥5%) (Choose first condition that fits)	EPAN Layer Group	459
5a.	The above species dominant	EPAN-EPAN Layer Type	459.459
5b.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) dominant or codominant	EPAN-APAN Layer Type	459.415
5c.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii)* dominant or codominant	EPAN-FRVE Layer Type	459.465
5d.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	EPAN-CAGE Layer Type	459.309
5e.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	EPAN-CARU Layer Type	459.307
5f.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	EPAN-THOC Layer Type	459.547
5.	*Epilobium* (incl. *Balsamorhiza, Geranium, Castilleja,* and *Penstemon attenuatus*) poorly represented (<5%)	6	
6.	*Apocynum androsaemifolium* (incl. *Pteridium* and *Veratrum*) well represented (≥5%) (Choose first condition that fits)	APAN Layer Group	415
6a.	The above species dominant	APAN-APAN Layer Type	415.415
6b.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) dominant or codominant	APAN-FRVE Layer Type	415.465
6c.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	APAN-CAGE Layer Type	415.309
6d.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	APAN-CARU Layer Type	415.307
6e.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	APAN-THOC Layer Type	415.547
6.	*Apocynum* (incl. *Pteridium* and *Veratrum*) poorly represented (5%)	7	
7.	*Fragaria vesca* (incl. *F. virginiana* and *Penstemon wilcoxii*) well represented (≥5%) (Choose first conditions that fits)	FRVE Layer Group	465
7a.	The above species dominant	FRVE-FRVE Layer Type	465.465
7b.	*Carex geyeri* (incl. *Aster conspicuus*) dominant or codominant	FRVE-CAGE Layer Type	465.309
7c.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	FRVE-CARU Layer Type	465.307
7d.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	FRVE-THOC Layer Type	465.547
7.	*Fragaria* spp. and *Penstemon* poorly represented (<5%)	8	
8.	*Carex geyeri* (incl. *Aster conspicuus*) well represented (≥5%)	CAGE Layer Group	309
8a.	The above species dominant	CAGE-CAGE Layer Type	309.309
8b.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium triflorum*) dominant or codominant	CAGE-CARU Layer Type	309.307
8c.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	CAGE-THOC Layer Type	309.547
8.	*Carex* and *Aster* poorly represented (<5%)	9	
9.	*Calamagrostis rubescens* (incl. *Arnica, Antennaria racemosa,* and *Galium trifolium*) well represented (≥5%) (Choose first condition that fits)	CARU Layer Group	307
9a.	The above species dominant	CARU-CARU Layer Type	307.307
9b.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) dominant or codominant	CARU-THOC Layer Type	307.547
9.	*Calamagrostis* (incl. *Arnica, Antennaria,* and *Galium*) poorly represented (<5%)	10	
10.	*Thalictrum occidentale* (incl. *Lathyrus nevadensis*) well represented (≥5%)	THOC Layer Group	547
10a.	The above species dominant	THOC-THOC Layer Type	547.547
10.	*Thalictrum* (incl. *Lathyrus*) poorly represented (<5%)	depauperate or unclassified layer type	

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[1] "Well represented" means canopy cover ≥5 percent.

[2] "Dominant" means greatest canopy cover.

[3] "Codominant" means canopy cover is nearly equal to that of another herb layer species.

ANNUALS LAYER GROUP (ANN. L.G.)

Annuals, mainly species of *Descurainia, Epilobium, Galium,* and *Gayophytum* and occasionally *Cryptantha,* can develop high coverages on newly exposed soil in full sunlight. These taxa have little competitive ability and their annual nature makes them vulnerable to replacement by any perennial. Likewise, biennials such as *Lactuca, Verbascum,* and *Cirsium vulgare* and the short-lived perennials *Phacelia* and *Gnaphalium* must reestablish frequently in order to maintain high coverages. Without recurring disturbance these taxa are also easily replaced as succession advances. Relative amounts of these early seral colonizers vary considerably following disturbance and appear to be mainly a function of available seed rather than the type of disturbance. The Annuals layer group represents the earliest seral conditions of the herb layer and is usually replaced within the first 5 years following disturbance; however, it can be maintained by intense livestock use.

Although not a sampling objective, Annuals layer types were frequently encountered in PSME/PHMA. Six out of the 10 possible layer types were sampled (fig. 15). Most of these resulted from clearcutting and scarification. The ANN.-ILRI and ANN.-CARU layer types resulted from clearcutting and broadcast burning; the other four resulted from clearcutting and scarification. In a few cases these layer types were surprisingly persistent, even where no grazing had occurred. An ANN.-BRCA layer type occurred on one site 15 years after the scarification, and an ANN.-CAGE layer type was present 17 years following site treatment.

BROMUS CARINATUS LAYER GROUP (BRCA L.G.)

Bromus carinatus is a nonrhizomatous grass that has little tolerance for shade and decreases under grazing, mainly from cattle. Occasionally, it develops high coverages in early seral stages either from direct seeding or natural colonization. In both cases, however, the sites receive little or no grazing. *Bromus inermis* is a rhizomatous grass that usually results from direct seeding. It too can develop high coverages on ungrazed sites. Like most grasses, these bromes store little or no seed in the soil (Kramer 1984; Strickler and Edgerton 1976). Both species can be used as indicators of this layer group. *Agropyron intermedium* can also achieve high coverages in PSME/PHMA from direct seeding and should be included in the BRCA layer group.

The BRCA layer group is not common in PSME/PHMA; only two of the nine possible layer types were found (fig. 15). In most if not all cases, these layer types resulted from direct seeding following wildfire (fig. 16) or scarification 5 to 13 years ago. None of these sites were being grazed. High coverages of seeded grasses are effective soil stabilizers following disturbance but can preclude establishment of other species including trees. Where high coverages of *Calamagrostis rubescens* exist prior to burning, the seeding of grasses may be unnecessary (Crane and others 1983).

POTENTILLA GLANDULOSA LAYER GROUP (POGL L.G.)

The perennial forb *Potentilla glandulosa* is nonrhizomatous and intolerant of shade. In full sunlight, it flowers

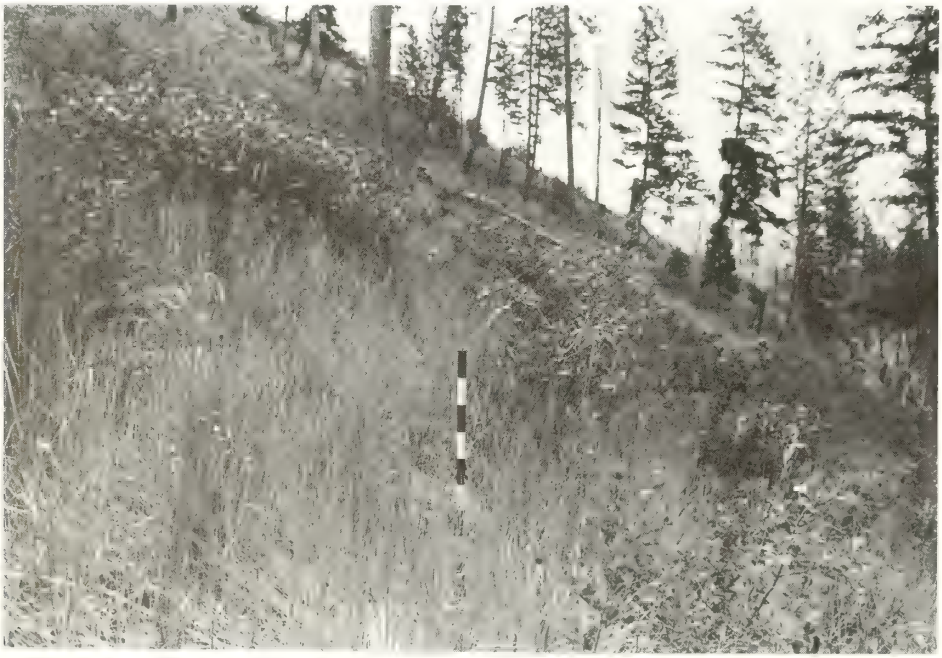

Figure 16—A BRCA-BRCA herb layer type east of Lowman, ID. This herb layer type was created by seeding the area following a wildfire 7 years ago. *Bromus inermis* and *Agropyron intermedium* now dominate the herb layer. *Iliamna* is the only other herbaceous species present in more than trace amounts. This herb layer type often precludes tree regeneration.

readily and produces large numbers of seed that store in the soil (Kramer 1984). The seeds often germinate profusely following scarification, which can result from either mechanical treatment of the site or heavy livestock use. This species of *Potentilla* seems to be less palatable to livestock than most associated herbs and can increase under grazing to the point of being the only species that is well represented on the site.

Agastache urticifolia is a nonrhizomatous, shade-intolerant forb, with seed that can be stored in the soil (Kramer 1984). It occasionally develops high coverages following scarification and appears to be a successional equivalent of *Potentilla*. Therefore, it is included as an alternate indicator of this layer group.

Rudbeckia occidentalis is a nonrhizomatous perennial with successional responses similar to those of *Potentilla*. One difference, however, is that *Rudbeckia* tends to be a more successful invader on basaltic soils than on granitics, whereas *Potentilla* is successful on both granitic and basaltic soils. Both soil types are common in PSME/PHMA.

Three of the eight possible layer types were found (fig. 15). These layer types represent early seral stages of herb layer succession and are mainly the result of scarification without burning. The POGL-FRVE layer type occurred on a site that had been broadcast burned and scarified. Initially, it may have been an ILRI layer type, but because of heavy grazing by sheep, only a trace of *Iliamna* was present. It is not uncommon for POGL layer types to result from grazing disturbance on sites that had been previously logged. Most sample stands in this layer group were disturbed less than 18 years ago (appendix C). These layer types will only persist until a shrub layer begins to shade the site.

ILIAMNA RIVULARIS LAYER GROUP (ILRI L.G.)

Iliamna rivularis is a nonrhizomatous early seral perennial. In full sun, it can flower profusely and produce seed that store in the soil for long periods (Kramer 1984). This species can become well represented following clearcutting and hot broadcast burning or where slash has been piled and burned (fig. 17). It may also appear following high-intensity wildfire. This response is common in other habitat types such as Douglas-fir/mountain maple (PSME/ACGL) but is currently rare in PSME/PHMA.

ILRI layer types were rarely found in PSME/PHMA (fig. 15) even though small amounts of *Iliamna* were often present in early seral herb layers. It appears that ILRI layer types could become more common on PSME/PHMA sites if high-intensity wildfires and broadcast burns occurred more often and allowed *Iliamna* to increase its coverage and seed with each disturbance. However, Kramer (1984) found no *Iliamna* seed in the 16 old-growth stands of PSME/PHMA that he sampled. Thus some stands do not have the potential at present to produce ILRI layer types from intense burning. It is not known whether this is due to unfavorable environment or site history.

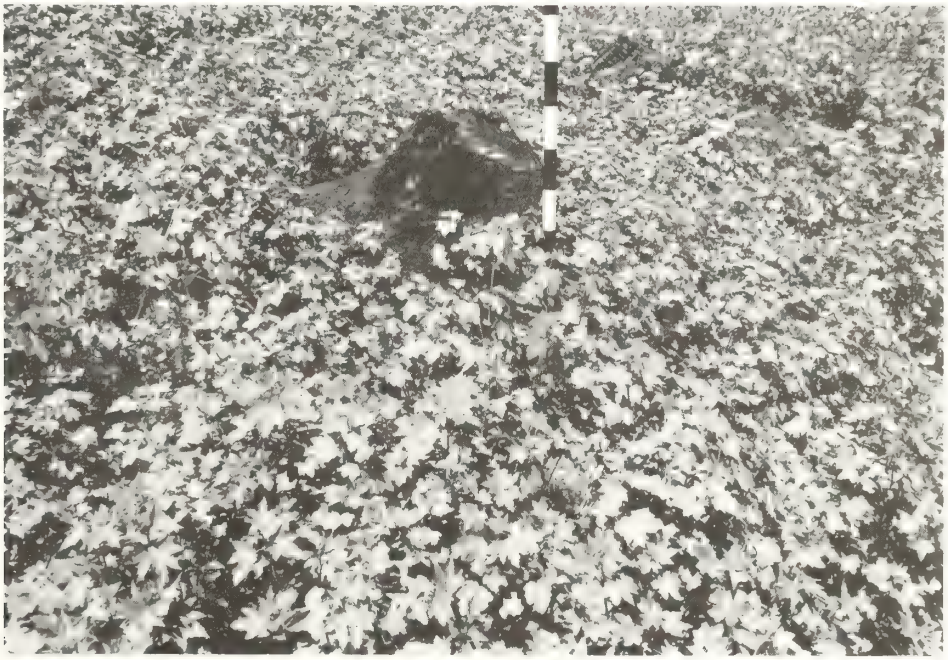

Figure 17—An ILRI-ILRI herb layer type north of Bogus Basin Ski Area. This area was clearcut and severely burned 2 years ago. *Iliamna* germinated profusely from seed buried in the soil and now dominates the site. In a few years the *Iliamna* will give way to a CEVE-CEVE shrub layer.

EPILOBIUM ANGUSTIFOLIUM LAYER GROUP (EPAN L.G.)

Epilobium angustifolium is a rhizomatous perennial that can establish readily from windblown seed. In open areas created by stand-destroying wildfire, it characteristically colonizes bare soil and forms extensive colonies that bloom profusely (Stickney 1985). *Epilobium*, however, does not always need burned areas for establishment. In clearcuts, it often appears on burned or unburned dozer-piled debris, where soil and debris have been mixed. Apparently the required substrate for *Epilobium* is deep, loose soil, usually exposed by either fire or logging.

Geranium viscosissimum is a nonrhizomatous forb that has some tolerance for light shade. It apparently increases when grazing, especially by sheep, has been reduced. At the dry extremes of PSME/PHMA, it occasionally becomes a notable component of ungrazed forb communities in mid-seral condition. Apparently *G. viscosissimum* has limited ability to store its seed in the soil and duff (Kramer 1984).

Balsamorhiza sagittata is a deep-rooted, nonrhizomatous forb that has some tolerance for light shade. Occasionally it becomes well represented in early- to mid-seral stages at the driest extremes of PSME/PHMA succession. Like *Geranium, Balsamorhiza* has only limited ability to store its seed in the soil and duff (Krygier 1955) and is considered to be successionally equivalent to *Geranium*. Because neither *Geranium* nor *Balsamorhiza* become well represented in most of the PSME/PHMA habitat type, they were subjectively grouped with *Epilobium*.

Castilleja miniata is a woody-based forb with some tolerance for light shade and grazing. In PSME/PHMA, it occasionally develops relatively high coverages in stands of patchy timber or scattered tall shrubs. In the Weiser River drainage, *Castilleja applegatei* may also be present on these sites and is considered a successional equivalent of *C. miniata*. Because of their sparse occurrence in PSME/PHMA, these *Castillejas* were subjectively grouped with *Epilobium* as indicators of mid-seral herb layers.

Penstemon attenuatus is a woody based perennial that forms small mats from a rhizome-caudex. It can apparently increase under light shade and light grazing but requires bare soil for establishment. Occasionally it becomes well represented on scarified sites in PSME/PHMA.

The EPAN layer group is fairly common in PSME/PHMA; four of the six possible layer types were found (fig. 15). About half of the sample plots in this layer group resulted from wildfire or broadcast burning, 6 to 55 years ago (fig. 18); the remainder resulted from scarification 8 to 15 years ago. Only one sample stand was receiving moderate grazing by sheep; the rest were receiving little or no grazing.

APOCYNUM ANDROSAEMIFOLIUM LAYER GROUP (APAN L.G.)

Apocynum is a rhizomatous forb that can develop a substantial coverage in full sun or partial shade. It is highly unpalatable to livestock and can withstand light to moderate grazing impacts. There is no indication that *Apocynum* seed will store in the soil (Kramer 1984).

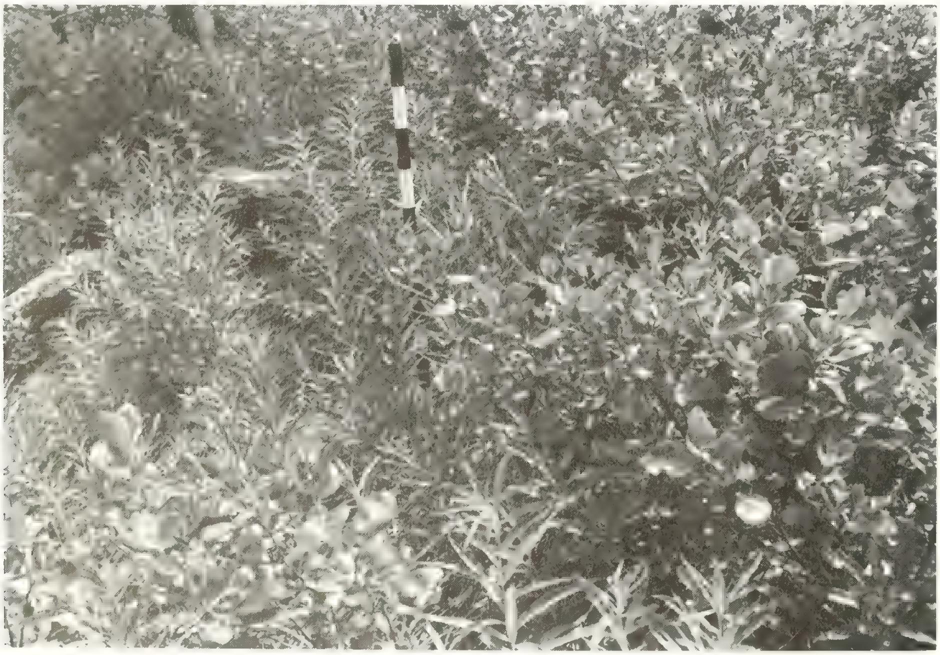

Figure 18—An EPAN-EPAN herb layer type northeast of New Centerville, ID. This site was burned 6 years ago by a wildfire of moderate intensity. *Epilobium angustifolium* is the only herb layer species that is well represented. Soon it will be over-topped by *Ceanothus*.

Veratrum californicum is a tall rhizomatous forb that can maintain substantial coverages beneath partial shade. Like *Apocynum*, it has low palatability to livestock and can withstand considerable grazing impact. Black bear, however, will eat the thick shoots, especially in late spring. *Veratrum*'s seed storage capability remains unknown. Occasionally it becomes well represented in PSME/PHMA and is considered an alternate indicator of the APAN layer group.

Pteridium is a rhizomatous fern capable of developing extensive colonies, especially with repeated burning. It can dominate forest openings for many decades, even without burning, and often maintains relatively pure stands. This latter trait has implicated *Pteridium* with allelopathic capability, a feature substantiated by Stewart (1975), Horsley (1977), and del Moral and Cates (1971). Apparently the senescent fronds produce the greatest inhibitory effects on certain herbaceous and woody vegetation. Recently, *Pteridium* has been shown to substantially inhibit conifers (Ferguson and Boyd 1988). Although it often grows vigorously in full sun, *Pteridium* can also increase under light shade but declines under a mature coniferous canopy. Although *Pteridium* occurs sporadically in PSME/PHMA, it was well represented in only one sample stand and so was grouped with *Apocynum* as an indicator of mid-seral herb layers.

The APAN layer group was not common in PSME/PHMA; only two of the five possible layer types were found. The sampled plots had been either burned by wildfire or scarified 18 to 50 years ago. It is likely that the APAN layer types are the result of successional advance rather than a direct response to disturbance. They may, however, develop directly from the Annuals layer group (ANN.-APAN) because both *Apocynum* and *Pteridium* can survive scarification and burning.

FRAGARIA VESCA LAYER GROUP (FRVE L.G.)

Fragaria vesca and *F. virginiana* can develop substantial coverages through their stoloniferous growth habit. This happens most frequently beneath a light canopy of trees or tall shrubs where partial shade has reduced competition from early seral herbs. Trampling from grazing animals can reduce the coverage of *Fragaria*, especially *F. vesca*. On the cutover sites that are being heavily grazed, *Fragaria* often achieves notable development beneath the protection of large shrubs, such as *Salix*, while the shrub interspaces contain mostly *Potentilla* and other species more tolerant of grazing. Although both species of *Fragaria* occur in PSME/PHMA, *F. vesca* is the most common. Kramer (1984) found small amounts of viable *Fragaria* seed stored in the soil, but birds and mammals likely disperse most of the seed. Apparently *Fragaria* needs bare shaded soil for seedling establishment.

Penstemon wilcoxii is a moderately shade-tolerant perennial that occasionally becomes well represented in PSME/PHMA. Like *Fragaria*, it too has small amounts of viable seed stored in the soil (Kramer 1984) and germinates well on bare, shaded soil. For classification purposes, *P. wilcoxii* was arbitrarily grouped with *Fragaria* as an alternate indicator of late mid-seral herb layers. But *P. wilcoxii* (with toothed leaves) must be distinguished from the less tolerant *P. attenuatus* (with entire leaves), which was grouped with *Epilobium*.

The FRVE layer group represents a mid-seral stage of herb layer succession and consists of four layer types in PSME/PHMA. Two of these have been sampled (fig. 15). Most of the FRVE layer types sampled appear to be the successional result of clearcut areas that were scarified 10 to 18 years ago. All sites were well shaded by shrubs. Little or no grazing was evident on most of these sites.

CAREX GEYERI LAYER GROUP (CAGE L.G.)

Carex geyeri is a moderately shade-tolerant sedge found in many habitat types. In PSME/PHMA, it tends to grow in a bunch form, especially on dry granitic substrates, but on more moist sites it can become rhizomatous and develop a sparse sod. *Carex geyeri* has an extensive root system in proportion to its foliar coverage. A stand of mature *Carex* can fully occupy the soil even though aboveground interspaces may be as much as 3 feet (0.9 m). This characteristic makes *C. geyeri* an important plant cover on many steep, erodible slopes, but it also presents formidible root competition for other plants, including tree seedlings. This sedge can resprout following light scarification, and its seed has some ability to store in the soil (Kramer 1984). The stored seed apparently germinates best following clearcutting and scarification. In spring, *C. geyeri* is one of the first plants to produce new growth which has considerable forage value for elk and black bear (appendix C).

Aster conspicuus is a moderately shade-tolerant forb that can maintain extensive colonies beneath pine and open canopies of Douglas-fir. It can increase vegetatively by rhizomes when the tree canopy is reduced, and it apparently also increases following creeping ground fire. Its windblown seed provides long-distance dispersal and probably germinates on bare soil. In this manner, small amounts of *Aster* can establish following stand-destroying wildfire, or clearcutting with scarification. The *Aster* can then increase vegetatively to form extensive colonies, which persist on well-timbered sites. For this reason, *Aster conspicuus* is considered successionally similar to *Carex geyeri* as an indicator of late seral conditions.

In PSME/PHMA, the CAGE layer group consists of three layer types; two of these were found (fig. 15). All of these sites had experienced a wildfire 16 to 125 years ago. Six of the sites had also experienced a clearcut with no site treatment 8 to 40 years ago, but the CAGE layer types involved merely survived the disturbance and did not result from it. These layer types most likely result from successional advance rather than direct response to disturbance. For classification purposes, the CAGE layer types are treated as late seral but in fact may be climax in drier portions of PSME/PHMA where *Calamagrostis*, *Arnica*, and *Thalictrum* have little or no potential.

CALAMAGROSTIS RUBESCENS LAYER GROUP (CARU L.G.)

Calamagrostis rubescens is a rhizomatous grass that can maintain high coverages under moderate shade as well as in openings. If well established, it can easily survive the impacts of clearcutting and broadcast burning.

With increased sunlight, *Calamagrostis* can renew its vigor and easily dominate the herb layer. The resulting sod presents severe competition for tree seedlings and requires either chemical or mechanical treatment for adequate tree seedling survival. The spring-summer forage value of *Calamagrostis* is considered high for black bear and elk (appendix C).

Arnica cordifolia is a shade-tolerant rhizomatous forb that can develop substantial coverages in clearcuts or beneath open stands of timber. But on most PSME/PHMA sites, *Arnica* displays low coverages beneath a shrub or tree canopy and persists in moderate shade more successfully than most other herb layer species. It shows little ability to increase from seed following any type of disturbance and, like most wind-dispersed species, does not store its seed in the soil (Kramer 1984). *Arnica* increases most effectively from residual plants following partial cutting without scarification, and it has moderate forage value for deer and elk (appendix C).

The CARU layer group consists of two layer types in PSME/PHMA, and both were found (fig. 15). Most of these sites had received little or no disturbance since the last wildfire 40 to 146 years ago. A few sites had experienced a timber harvest, but the impacts were too slight to alter the herb layer. The CARU layer types usually result from successional advance. It is not likely that they can generate directly from site treatment. In some cases, ineffective site treatment may allow a preexisting CARU layer type to remain intact and create a difficult situation for tree regeneration.

THALICTRUM OCCIDENTALE LAYER GROUP (THOC L.G.)

Thalictrum occidentale is a shade-tolerant rhizomatous forb that occasionally produces high coverages in PSME/PHMA. *Thalictrum fendleri* may also be present. It appears to be successionally equivalent to *T. occidentale* and so is included with that species. No other species in the herb layer appears capable of replacing *Thalictrum* without the aid of disturbance. The *Thalictrum* coverage can be reduced by moderate scarification, burning, and in some cases, just removal of the tree canopy. *Thalictrum* does not appear capable of storing its seed in the soil (Kramer 1984) and has little or no forage value for big game and livestock (appendix C).

The THOC layer group consists of one layer type and is considered climax wherever found in PSME/PHMA. It usually results from successional advance and is not apt to be generated directly from site treatment. In some cases, however, ineffective site treatment may allow a preexisting THOC layer type to remain intact. This layer type was found mainly on sites that had not been disturbed for 50 to 100 years. One site had been recently logged, but *Thalictrum* had survived the disturbance. None of these sites were being grazed.

MANAGEMENT IMPLICATIONS

Management implications of the herbaceous layer focus on relative forage values to big game and livestock. A relative index to forage preferences by herb layer type was developed by the same method used for the shrub layer (see shrub layer for details). Range and wildlife managers who have better palatability ratings for a local area can easily recalculate the forage preference indexes from appendix C. Users of table 19 should consider the often small sample size of some layer types and possible revision of index values with increased sampling. As more data become available, these forage preference indexes can provide general guidelines to grazing potential for specific management objectives. When both herb and shrub layer types are known for a given site, the index values assigned in table 19 can be added to those in table 9 to give a total forage index for that site.

Deer—Herb layer forage values for deer in summer are generally low throughout PSME/PHMA succession. Two exceptions are the ANN.-ILRI and POGL-FRVE herb layer types which have moderate value (table 19). These higher values hinge mainly on higher coverages of *Iliamna* and *Fragaria*, which have moderate palatability for deer (appendix C). High coverages of *Iliamna* can only be achieved through high-intensity burning. High coverages of *Fragaria* are best achieved through successional advance of well-scarified, partially shaded sites.

Forage values for deer in winter are low to nil; the only exception being POGL-FRVE, which has moderate value. This higher value is again due to high coverages of *Fragaria*, which often retains green leaves beneath the snow and has moderate palatability for deer in winter.

Elk—Forage values for elk in summer are mostly low in PSME/PHMA herb layers. Only the ANN.-BRCA, ANN.-ILRI, and FRVE-CARU layer types have moderate value (table 19). High coverages and palatability of *Bromus carinatus, Iliamna*, and *Calamagrostis* are mainly responsible for these higher forage values (appendix C). All of these species are favored by burning. *Bromus carinatus* will also colonize scarified areas and responds well to direct seeding.

Forage values for elk in winter are low to nil except for the POGL-FRVE layer type, which has moderate value. The moderate winter forage value of *Fragaria* is mainly responsible for the higher index of POGL-FRVE.

Cattle—Forage values for cattle are generally low in all stages of PSME/PHMA succession (table 19). The only exception is the ANN.-ILRI layer type, which has moderate value due to the high coverage and moderate palatability of *Iliamna*. This species can be generated from buried seed by intense burning. But *Iliamna* seed is not always present on PSME/PHMA sites, and intense burning also generates high coverages of *Ceanothus*, which often deters cattle use of the site.

Sheep—Most herb layer types in PSME/PHMA have low forage value for sheep. Only the ANN.-ILRI, POGL-FRVE, and FRVE-CARU layer types have moderate value. These three layer types also ranked highest in value for either deer or elk (table 19). This suggests that some competition between wildlife and livestock exists for the forage resource in the herb layer.

Table 19—Relative index classes of big-game and livestock forage preferences by herb layer types in the PSME/PHMA h.t., PIPO phase[1]

Layer group layer type	No. of stands	Deer		Elk		Cattle	Sheep	Black bear		
		SU[2]	W	SU	W	SU	SU	SP	SU	F
Annuals										
ANN.-ANN.	3	[3]1	0	1	0	1	1	0	0	0
ANN.-BRCA	2	2	1	3	1	2	2	1	0	0
ANN.-POGL	2	1	0	1	0	1	1	0	0	0
ANN.-ILRI	1	3	0	4	0	3	4	0	0	0
ANN.-CAGE	1	1	0	2	1	2	2	1	0	0
ANN.-CARU	1	0	0	1	0	0	1	1	0	0
Bromus carinatus										
BRCA-BRCA	3	1	1	1	1	2	1	0	0	0
BRCA-FRVE	1	2	1	2	1	2	2	0	0	0
Potentilla glandulosa										
POGL-POGL	5	1	0	1	1	1	1	0	0	0
POGL-EPAN	2	2	1	2	1	1	2	0	0	0
POGL-FRVE	1	4	3	2	3	2	4	1	4	1
Iliamna rivularis										
ILRI-ILRI	1	1	0	1	0	1	1	0	0	0
Epilobium angustifolium										
EPAN-EPAN	3	1	1	1	1	1	1	0	0	0
EPAN-APAN	1	2	1	2	1	1	2	0	0	0
EPAN-CARU	2	1	1	2	1	1	1	1	0	0
EPAN-THOC	1	1	1	2	1	1	1	0	0	0
Apocynum androsaemifolium										
APAN-APAN	2	1	0	1	0	1	1	0	0	0
APAN-CAGE	1	2	1	2	2	2	2	1	1	1
Fragaria vesca										
FRVI-CAGE	1	2	2	2	2	2	2	1	2	1
FRVI-CARU	3	2	2	3	2	2	3	2	2	1
Carex geyeri										
CAGE-CAGE	21	1	1	2	2	2	1	2	1	1
CAGE-CARU	5	1	1	2	1	2	1	1	1	0
Calamagrostis rubescens										
CARU-CARU	25	1	1	2	1	1	1	1	1	0
CARU-THOC	2	1	0	2	0	1	1	0	0	0
Thalictrum occidentale										
THOC-THOC	10	1	0	1	0	1	1	0	0	0

[1] Based on palatability ratings by Kufeld (1973), Kufeld and others (1973), USDA FS (1986), and Beecham (1981).

[2] SP = spring (March, April, May); SU = summer (June, July, August); F = fall (September, October, November); W = winter (December, January, February).

[3] Code to index classes:
0 = 0-50; 1 = 51-150; 2 = 151-250 (low)
3 = 251-350; 4 = 351-450; 5 = 451-550 (moderate)
6 = 551-650; 7 = 651-750; 8 = 751-850 (high).

Black Bear—Forage values for black bear are low to nil in all herb layer types except POGL-FRVE (table 7). The moderate forage value of POGL-FRVE depends mainly on production of *Fragaria* fruits in the summer. This fruiting, however, may not be consistent nor proportional to the *Fragaria* cover as the forage index suggests.

Pocket Gophers—Some relationships between pocket gopher populations and silvicultural activities were previously discussed (see tree layer section). Scarification without burning resulted in the most gopher activity (table 4). Scarification generally produces early seral herb layers that classify as being in the Annuals and POGL herb layer groups (fig. 19). Apparently herb layers in these two groups stimulate gopher populations. The scarification can result from either machinery or heavy livestock use and may account for the observed correlation between heavy grazing and high gopher activity in other areas (Buechner 1942). The relationship between gopher activity and early seral herb layers created by scarification without burning was also found in other habitat types (Steele and Geier-Hayes 1985, 1986). Other types of disturbance, such as broadcast burning, generally result in either a depauperate or more successionally advanced herb layer type and often result in less gopher activity.

In summarizing studies of pocket gophers, Teipner and others (1983) suggest that plant species composition and abundance are the main regulators of gopher density. More specifically, Andersen and MacMahon (1981) correlated gopher population decline in a spruce-fir forest with decreasing palatable vegetation due to advancing successional stages. Succession in PSME/PHMA, especially the herbaceous layer, also appears related to gopher activity. Here occurrence and number of gopher mounds were tallied in either a 50-m^2 or a 375-m^2 circular plot and summarized according to herb layer type. Because not all gopher activity results in new mounds, the number of mounds may not reflect actual gopher density throughout the soil profile but should indicate relative activity between sites in the upper soil profile where feeding occurs. Teipner and others (1983) note several studies in which number of mounds indicated the relative abundance of gophers.

Figure 20 shows that relative gopher activity is highest in early seral herbaceous layers, especially the Annuals, BRCA, and POGL layer groups, and is considerably less in the late seral to climax conditions. This trend is similar to that found by Andersen and MacMahon (1981) and suggests that certain early seral species may provide the greatest benefit to gophers. In laboratory feeding tests, gophers gained weight on exclusive diets of both *Taraxacum* and *Erigeron*, and their subsistence was marginal on *Bromus carinatus* and *Bromus inermis* (Tietjen and others 1967). All of these taxa would be considered early seral species in PSME/PHMA (fig. 20). In contrast, gophers died on exclusive diets of *Geranium* (Tietjen and others 1967) and *Epilobium angustifolium* (Andersen and MacMahon 1985), both of which are mid-seral species. Although inconclusive at this point, additional feeding tests using a wider variety of plant species may substantiate this trend and show what kinds of herb layers are best suited for gopher control.

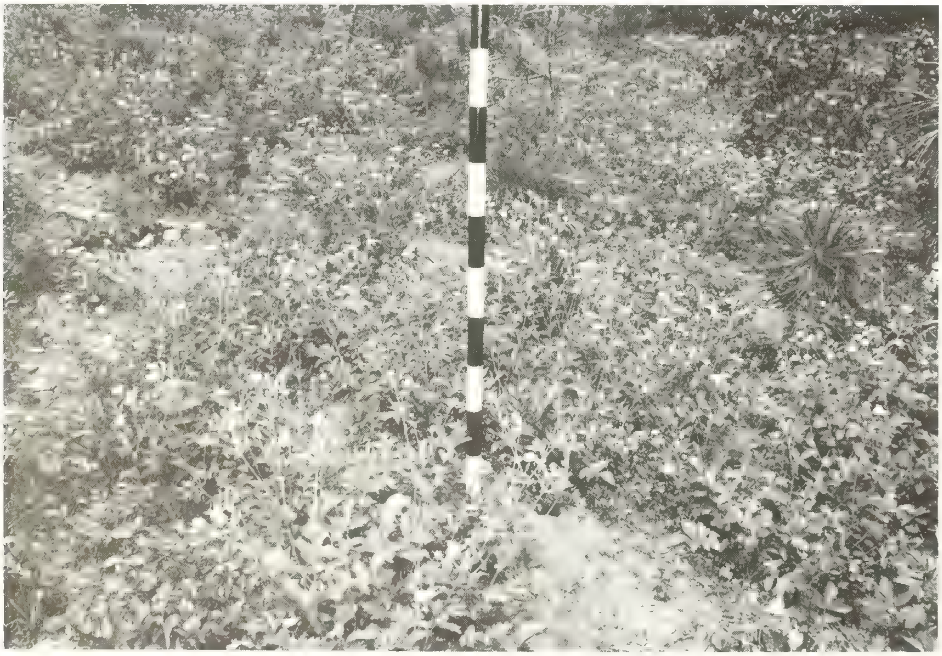

Figure 19—A POGL-POGL herb layer type supporting a high level of pocket gopher activity. This site was clearcut and thoroughly scarified 18 years ago. The *Potentilla* germinated from buried seed in response to the scarification. These POGL herb layer types generally support more gopher activity than most other herb layers in PSME/PHMA.

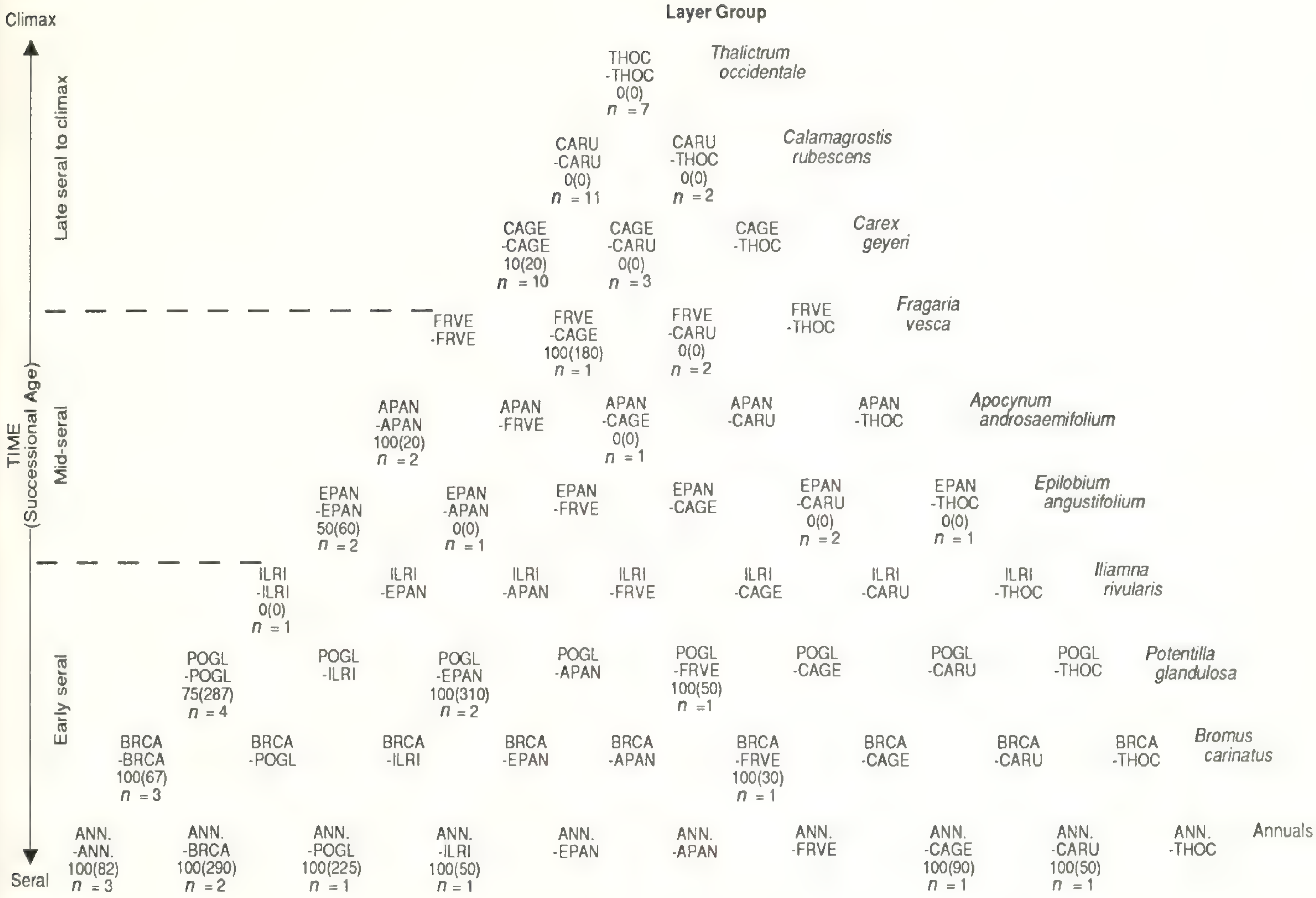

Figure 20—Constancy and average number per acre of pocket gopher mounds in various herb layer types (*n* = number of samples in each layer type).

REFERENCES

Andersen, D. C.; MacMahon, J. A. 1981. Population dynamics and bioenergetics of a fossorial herbivore, *Thomomys talpoides* (Rodentia:Geomyidae), in a spruce-fir sere. Ecological Monographs. 51: 179-202.

Andersen, D. C.; MacMahon, J. A. 1985. Plant succession following the Mount St. Helens volcanic eruption: facilitation by a burrowing rodent, *Thomomys talpoides*. American Midland Naturalist. 114: 62-69.

Arno, S. F. 1976. The historical role of fire on the Bitterroot National Forest. Res. Pap. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 29 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession of four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Bazzaz, F. A. 1979. The physiological ecology of plant succession. Annual Review of Ecology and Systematics. 10: 351-371.

Beecham, J. 1981. Black bear food preference ratings. Report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Boise, ID.

Brickell, J. E. 1970. Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. Res. Pap. INT-75. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Brinkman, K. A. 1974. *Salix* L. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 746-750.

Brinkman, K. A.; Roe, E. I. 1975. Quaking aspen: silvics and management in the Lake States. Agric. Handb. 486. Washington, DC: U.S. Department of Agriculture, Forest Service. 52 p.

Buechner, H. K. 1942. Interrelationships between the pocket gopher and land use. Journal of Mammalogy. 23(3): 346-348.

Cholewa, A. F. 1977. Successional relationship of vegetational composition to logging, burning and grazing in the Douglas-fir/*Physocarpus* habitat type of northern Idaho. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 60 p. Thesis.

Cooper, S.; Neiman, K.; Steele R.; Roberts, D. W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Crane, M. F.; Habeck, J. R.; Fischer, W. C. 1983. Early postfire revegetation in a western Montana Douglas-fir forest. Res. Pap. INT-319. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Curtis, J. D.; Coonrod, M. A. 1960. The Town Creek ponderosa pine plantations. In: Proceedings, Society of American Foresters; 1960 November 13-16; Washington, DC. Washington, DC: Society of American Foresters: 21-24.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22: 301-330.

Daubenmire, R. A. 1973. A comparison of approaches to the mapping of forest land for intensive management. Forestry Chronicle. 49(2): 87-91.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agriculture Experiment Station. 104 p.

del Moral, R.; Cates, R. G. 1971. Allelopathic potential of the dominant vegetation of western Washington. Ecology. 52: 1030-1037.

Dingle, R. W. 1956. Pocket gophers as a cause of mortality in eastern Washington pine plantations. Journal of Forestry. 54(12): 832-835.

Ferguson, Dennis E.; Boyd, Raymond J. 1988. Bracken fern inhibition of conifer regeneration in northern Idaho. Res. Pap. INT-388. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Foiles, M. W.; Curtis, J. D. 1973. Regeneration of ponderosa pine in the Northern Rocky Mountain-Intermountain Region. Res. Pap. INT-145. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 44 p.

Geier-Hayes, K. 1987. Occurrence of conifer seedlings and their microenvironments on disturbed sites in central Idaho. Res. Pap. INT-383. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p.

Gratkowski, H. J. 1962. Heat as a factor in germination of seeds of *Ceanothus velutinus* var. *laevigatus* T. and G. Corvallis, OR: Oregon State University. 122 p. Dissertation.

Grisez, T. J. 1974. *Prunus* L. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 658-673.

Hall, F. C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southwestern Washington. R-6 Area Guide 3-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 62 p.

Hall, D. O.; Curtis, J. D. 1970. Planting method affects height growth of ponderosa pine in central Idaho. Res. Note INT-125. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Heisey, R. M.; Delwiche, C. C. 1983. A survey of California plants for water-extractable and volatile inhibitors. Botanical Gazette. 144(3): 382-390.

Hess, K. 1981. Phyto-edaphic study of habitat types of the Arapaho-Roosevelt National Forest, Colorado. Fort Collins, CO: Colorado State University. 558 p. Dissertation.

Hoffman, G. R.; Alexander, R. R. 1976. Forest vegetation of the Bighorn Mountains, Wyoming: a habitat type classification. Res. Pap. RM-170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.

Horsley, S. B. 1977. Allelopathic inhibition of black cherry by fern, grass, goldenrod, and aster. Canadian Journal of Forest Research. 7: 205-216.

Johnson, C. G., Jr.; Simon, S. A. 1987. Plant associations of Wallowa-Snake Province, Wallowa-Whitman National Forest. R6-ECOL-TP-255A-86. Baker, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest. 400 p.

Kramer, N. B. 1984. Mature forest seed banks of three habitat types in central Idaho. Moscow, ID: University of Idaho. 107 p. Thesis.

Krygier, J. T. 1955. Seeds in the forest floor of the ponderosa pine type. Logan, UT: Utah State University. 54 p. Thesis.

Kufeld, R. C. 1973. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 26: 106-113.

Kufeld, R. C.; Wallmo, O. C.; Feddema, C. 1973. Foods of the Rocky Mountain mule deer. Res. Pap. RM-11. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Lanner, R. M. 1980. Avian seed dispersal as a factor in the ecology and evolution of limber and whitebark pines. In: Dancik, B.; Higginbotham, K., ed. 6th North American forest biology workshop: Symposium proceedings; 1980 August 11-13; Edmonton, AB. Edmonton, AB: University of Alberta: 15-48.

Layser, E. F. 1974. Vegetative classification: its application to forestry in the northern Rocky Mountains. Journal of Forestry. 72: 354-357.

Lynch, D. W. 1958. Effects of stocking on site measurement and yield of second-growth ponderosa pine in the Inland Empire. Res. Pap. 56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 36 p.

Mauk, R. L.; Henderson, J. A. 1984. Coniferous forest habitat types of northern Utah. Gen. Tech. Rep. INT-170. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 89 p.

McConkie, A. R.; Mowat, E. L. 1936. A preliminary study of factors affecting establishment of ponderosa pine and Douglas-fir seedlings in central Idaho. Interim report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Boise, ID. 66 p.

Medin, D. E. 1984. [Personal communication]. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory.

Megahan, W. F.; Steele, R. 1987. An approach for predicting snow damage to ponderosa pine plantations. Forest Science. 33(2): 485-503.

Minore, D. 1979. Comparative autecological characteristics of northwestern tree species - a literature review. Gen. Tech. Rep. PNW-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 72 p.

Monserud, R. A. 1985. Applying height growth and site index curves for Inland Douglas-fir. Res. Pap. INT-347. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Moore, A. W. 1943. The pocket gopher in relation to yellow pine reproduction. Journal of Mammalogy. 24(2): 271-273.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Oliver, W. W. 1970. Snow bending of sugar pine and ponderosa pine seedlings . . . injury not permanent. Res. Note PSW-225. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 3 p.

Pfister, R. D. 1984. Forest habitat type classification in the western United States. In: Grey, D. C.; Schonau, A. P. G.; Scholtz, L. S., eds. Symposium on site and productivity of fast growing plantations. IUFRO proceedings; 1984 April 30-May 11; Pretoria and Pietermaritzburg, South Africa. Pretoria, South Africa: South African Forest Research Institute: 149-162.

Pfister, R. D.; Kovalchik, B.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Poore, M. E. D. 1962. The method of successive approximation in descriptive ecology. Advances in Ecological Research. 1: 35-68.

Rehfeldt, G. E. 1986. Adaptive variation in *Pinus ponderosa* from Intermountain Regions. I. Snake and Salmon River Basins. Forest Science. 32(1): 79-92.

Rehfeldt, G. E. 1987. Components of adaptive variation in *Pinus contorta* from the Inland Northwest. Res. Pap. INT-375. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11p.

Rehfeldt, G. E.; Cox, R. G. 1975. Genetic variation in a provenance test of 16-year-old ponderosa pine. Res. Note INT-201. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

Richens, V. B. 1965. An evaluation of control on the Wasatch pocket gopher. Journal of Wildlife Management. 29(30): 413-425.

Silen, R. R.; Rowe, K. E. 1971. Inheritance of stockiness in ponderosa pine families. Res. Note PNW-166. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

Steele, R.; Arno, S. F.; Geier-Hayes, K. 1986. Wildfire patterns change in central Idaho's ponderosa pine-Douglas-fir forest. Western Journal of Applied Forestry. 1: 16-18.

Steele, R.; Geier-Hayes, K. 1984. The Douglas-fir/pinegrass habitat type in central Idaho: succession and management. Preliminary draft. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 124 p.

Steele, R.; Geier-Hayes, K. 1985. The grand fir/mountain maple habitat type in central Idaho: succession and management. Preliminary draft. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 118 p.

Steele, R.; Geier-Hayes, K. 1986. The Douglas-fir/white spiraea habitat type in central Idaho: succession and management. Preliminary draft. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 96 p.

Steele, R.; Geier-Hayes, K. 1987a. The Douglas-fir/elk sedge habitat type in central Idaho: succession and management. Preliminary draft. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 111 p.

Steele, R.; Geier-Hayes, K. 1987b. The grand fir/blue huckleberry habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 170 p.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Steele, R.; Cooper, S. V.; Ondov, D. M.; Roberts, D. W.; Pfister, R. D. 1983. Forest habitat types of eastern Idaho and western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

Stewart, R. E. 1975. Allelopathic potential of western bracken. Journal of Chemical Ecology. 1: 161-169.

Stickney, P. F. 1980. Data base for post-fire succession, first 6 to 9 years in Montana larch-fir forests. Gen. Tech. Rep. INT-62. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 133 p.

Stickney, P. F. 1985. Data base for early post-fire succession on the Sundance Burn, northern Idaho. Gen. Tech. Rep. INT-189. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 121 p.

Strickler, G. S.; Edgerton, P. J. 1976. Emergent seedlings from coniferous litter and soil in eastern Oregon. Ecology. 57: 801-807.

Teipner, C. L.; Garton, E. O.; Nelson, L., Jr. 1983. Pocket gophers in forest ecosystems. Gen. Tech. Rep. INT-154. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

Teitjen, H. P.; Halvorsen, C. M.; Hegdal, P. L.; Johnson, A. M. 1967. 2,4-D herbicide, vegetation, and pocket gopher relationships: Black Mesa, Colorado. Ecology. 48(4): 634-643.

U.S. Department of Agriculture, Forest Service. 1940. Annual report of Intermountain Forest and Range Experiment Station for 1940. On file at: Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 120 p.

U.S. Department of Agriculture, Forest Service. 1986. Region 4 - Range Analysis Handbook. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT.

West, N. E. 1968. Rodent-influenced establishment of ponderosa pine and bitterbrush seedlings in central Oregon. Ecology. 49: 1009-1011.

Youngberg, C. T.; Wollum, A. G.; Scott, W. 1979. *Ceanothus* in Douglas-fir clear-cuts: nitrogen accretion and impact on regeneration. In: Gordon, J. C.; Wheeler, C. T.; Perry, C. T., eds. Symbiotic nitrogen fixation in the management of temperate forests: Workshop proceedings; 1979 April 2-5; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory. 224-233.

Youngblood, A. P.; Mauk, R. L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

Younger, P. D.; Kock, R. G.; Kapustka, L. R. 1980. Allelochemic interference by quaking aspen leaf litter on selected herbaceous species. Forest Science. 26(3): 429-434.

Zavitkovski, J.; Newton, M. 1968. Ecological importance of snowbrush, *Ceanothus velutinus*, in the Oregon Cascades. Ecology. 49: 1134-1145.

Zavitkovski, J.; Woodard, E. S. 1970. Role of brush in ponderosa pine establishment. In: Herman, R. K., ed. Regeneration of ponderosa pine. Corvallis, OR: Oregon State University, School of Forestry: 100-104.

APPENDIX A: CONSTANCY[1] AND AVERAGE CANOPY COVER (PERCENT) OF TREES BY LAYER TYPE IN THE PSME/PHMA H.T., PIPO PHASE, SHOWING SIZE CLASS DISTRIBUTION AND AVERAGE BASAL AREA

TREE LAYER GROUP		*Populus tremuloides*											
Tree layer type		POTR - POTR											
Size class notation		s. POTR - s. POTR				s. POTR - p. POTR				p. POTR - m. POTR			
Number of stands		*n* = 1				*n* = 2				*n* =1			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	—	—	—	10(3.0)	—	—	—	—	—	—	—	—
014	*Populus tremuloides*	—	—	—	10(15.0)	—	—	10(37.5)	10(15.0)	—	—	10(37.5)	—
016	*Pseudotsuga menziesii*	—	—	—	—	—	—	—	—	—	—	—	10(0.5)
Average basal area (ft²/acre)		4				—				92			

TREE LAYER GROUP		*Pinus ponderosa*											
Tree layer type		PIPO - PIPO											
Size class notation		s. PIPO - s. PIPO				s. PIPO - p. PIPO				s. PIPO - o.g. PIPO			
Number of stands		*n* = 16				*n* = 2				*n* = 1			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	—	1(3.0)	4(3.0)	10(19.0)	—	5(3.0)	10(15.0)	10(15.0)	10(37.5)	—	10(3.0)	10(15.0)
014	*Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016	*Pseudotsuga menziesii*	—	—	1(3.0)	5(1.1)	—	—	5(3.0)	10(7.8)	10(3.0)	—	10(15.0)	10(15.0)
Average basal area (ft²/acre)		12				—				250			

TREE LAYER GROUP		*Pinus ponderosa*											
Tree layer type		PIPO - PIPO											
Size class notation		p. PIPO - p. PIPO				p. PIPO - m. PIPO				p. PIPO - o.g. PIPO			
Number of stands		*n* = 7				*n* = 1				*n* = 2			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	—	1(15.0)	10(21.4)	9(2.1)	—	10(37.5)	10(15.0)	—	10(26.0)	—	10(15.0)	5(3.0)
014	*Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016	*Pseudotsuga menziesii*	1(15.0)	—	4(7.0)	7(2.0)	—	10(10.0)	—	10(15.0)	—	—	10(1.2)	—
Average basal area (ft²/acre)		—				302				136			

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[1] Code to constancy values:

+ = 0 - 5%
1 = 5 - 15%
2 = 15 - 25%
3 = 25 - 35%
4 = 35 - 45%
5 = 45 - 55%
6 = 55 - 65%
7 = 65 - 75%
8 = 75 - 85%
9 = 85 - 95%
10 = 95 - 100%

(con.)

APPENDIX A (Con.)[1]

TREE LAYER GROUP	Pinus ponderosa											
Tree layer type	PIPO - PIPO				PIPO - PSME							
Size class notation	o.g. PIPO - o.g. PIPO				s. PIPO - s. PSME				p. PIPO - p. PSME			
Number of stand	*n* = 4				*n* = 2				*n* = 7			
Size classes (inches)	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>16	18 - 12	12 - 4	<4
ADP No. Tree species												
013 *Pinus ponderosa*	10(32.0)	2(3.0)	2(3.0)	10(1.1)	—	—	10(6.0)	10(15.0)	1(15.0)	3(17.5)	10(15.0)	9 (1.8)
015 *Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016 *Pseudotsuga menziesii*	2(15.0)	2(10.0)	8(7.0)	8(6.2)	—	5(3.0)	10(3.0)	10(15.0)	1 (3.0)	6(16.2)	10(25.7)	9 (4.2)
Average basal area (ft²/acre)		204				28				103		

TREE LAYER GROUP	Pinus ponderosa											
Tree layer type	PIPO - PSME											
Size class notation	p. PIPO - m. PSME				p. PIPO - o.g. PSME				m. PIPO - p. PSME			
Number of stands	*n* = 2				*n* = 1				*n* = 1			
Size classes (inches)	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No. Tree species												
013 *Pinus ponderosa*	—	5(15.0)	10(26.2)	10(1.8)	—	10(15.0)	10(15.0)	10(3.0)	—	10(15.0)	10(3.2)	—
014 *Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016 *Pseudotsuga menziesii*	—	10(37.5)	10(7.8)	10(7.8)	10(37.5)	—	10(15.0)	10(15.0)	10(3.0)	10(3.0)	10(20.0)	10(10.0)
Average basal area (ft²/acre)		112				62				95		

TREE LAYER GROUP	Pinus ponderosa											
Tree layer type					PIPO - PSME							
Size class notation	m. PIPO - m. PSME				o.g. PIPO - s. PSME				o.g. PIPO - p. PSME			
Number of stands	*n* = 3				*n* = 6				*n* = 6			
Size classes (inches)	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No. Tree species												
013 *Pinus ponderosa*	3(15.0)	10(15.0)	7(1.8)	7(1.8)	10(26.2)	2(3.0)	3(3.0)	5(2.2)	10(15.8)	3 (3.0)	3(3.0)	5(2.2)
014 *Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016 *Pseudotsuga menziesii*	10(15.0)	10(37.5)	10(15.0)	7(9.0)	3(15.0)	—	8(14.0)	10(24.6)	3(9.0)	10 (4.2)	0(22.5)	10(6.6)
Average basal area (ft²/acre)		204				149				176		

[1] Code to constancy values:

+ = 0 - 5%
1 = 5 - 15%
2 = 15 - 25%
3 = 25 - 35%
4 = 35 - 45%
5 = 45 - 55%
6 = 55 - 65%
7 = 65 - 75%
8 = 75 - 85%
9 = 85 - 95%
10 = 95 - 100%

(con.)

APPENDIX A (Con.)[1]

TREE LAYER GROUP		*Pinus ponderosa*								*Pseudotsuga menziesii*			
Tree layer type						PIPO - PSME				PSME - PSME			
Size class notation		o.g. PIPO - m. PSME				o.g. PIPO - o.g. PSME				s. PSME - s. PSME			
Number of stands		*n* = 1				*n* = 1				*n* = 6			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	10(15.0)	—	—	—	10(15.0)	10(3.0)	—	—	—	2(3.0)	2(3.0)	10(1.3)
014	*Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016	*Pseudotsuga menziesii*	—	10(15.0)	—	—	10(15.0)	—	10(3.0)	10(0.5)	3(9.0)	2(15.0)	10(6.4)	10(25.4)
Average basal area (ft²/acre)		74				204				58			

TREE LAYER GROUP						*Pseudotsuga menziesii*							
Tree layer type						PSME - PSME							
Size class notation		s. PSME - p. PSME				s. PSME - o.g. PSME				p. PSME - p. PSME			
Number of stands		*n* = 7				*n* = 2				*n* = 5			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	—	—	3(1.8)	4(1.3)	—	—	—	5(0.5)	—	2(0.5)	6(3.0)	6(1.3)
014	*Populus tremuloides*	—	—	—	—	—	—	—	—	—	—	—	—
016	*Pseudotsuga menziesii*	3(15.0)	7(11.6)	10(28.9)	10(15.0)	10(26.2)	5(3.0)	10(9.0)	10(15.0)	2(15.0)	—	10(17.5)	10(2.0)
Average basal area (ft²/acre)		119				70				109			

TREE LAYER GROUP						*Pseudotsuga menziesii*							
Tree layer type						PSME - PSME							
Size class notation		p. PSME - m. PSME				p. PSME - o.g. PSME				m. PSME - o.g. PSME			
Number of stands		*n* = 7				*n* = 3				*n* = 2			
Size classes (inches)		>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4	>18	18 - 12	12 - 4	<4
ADP No.	**Tree species**												
013	*Pinus ponderosa*	—	4(3.0)	3(3.0)	3(0.5)	—	—	—	7(0.5)	—	—	—	5(3.0)
014	*Populus tremuloides*	—	—	—	—	—	—	—	3(0.5)	—	—	—	—
016	*Pseudotsuga menziesii*	7(12.6)	10(25.7)	10(14.3)	10(1.9)	10(24.2)	3(15.0)	10(15.0)	7(1.8)	10(26.2)	10(26.2)	10(3.0)	10(1.8)
Average basal area (ft²/acre)		115				157				211			

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[1] Code to constancy values:

+ = 0 - 5%	2 = 15 - 25%	4 = 35 - 45%	6 = 55 - 65%	8 = 75 - 85%	10 = 95 - 100%
1 = 5 - 15%	3 = 25 - 35%	5 = 45 - 55%	7 = 65 - 75%	9 = 85 - 95%	

(con.)

APPENDIX A (Con.)[1]

TREE LAYER GROUP		*Pseudotsuga menziesii*			
Tree layer type		PSME - PSME			
Size class notation		o.g. PSME - o.g. PSME			
Number of stands		*n* = 1			
Size classes (inches)		**>18**	**18 - 12**	**12 - 4**	**<4**
ADP No.	**Tree species**				
013	*Pinus ponderosa*	10 (3.0)	—	—	—
014	*Populus tremuloides*	—	—	—	—
016	*Pseudotsuga menziesii*	10(15.0)	—	10 (3.0)	10(0.5)
Average basal area (ft²/acre)			197		

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[1] Code to constancy values:
+ = 0 - 5%
1 = 5 - 15%
2 = 15 - 25%
3 = 25 - 35%
4 = 35 - 45%
5 = 45 - 55%
6 = 55 - 65%
7 = 65 - 75%
8 = 75 - 85%
9 = 85 - 95%
10 = 95 - 100%

APPENDIX B-1: PALATABILITY RATINGS, CONSTANCY,[1] AND AVERAGE CANOPY COVER (PERCENT) OF SHRUBS BY LAYER TYPE IN THE PSME/PHMA H.T., PIPO PHASE

SHRUB LAYER GROUP										
Shrub layer type										
Number of stands										
	Palatability ratings[2]	**Deer**		**Elk**				**Black bear**		
		Summer	**Winter**	**Summer**	**Winter**	**Cattle**	**Sheep**	**Spring**	**Summer**	**Fall**
ADP No.	**Shrub species**									
102	*Acer glabrum*	4	6	6	6	4	4	0	0	0
105	*Amelanchier alnifolia*	4	4	6	6	3	5	2	6	6
203	*Berberis repens*	2	4	2	4	2	3	2	4	4
198	*Ceanothus sanguineus*	6	4	6	6	2	2	0	0	0
107	*Ceanothus velutinus*	6	4	6	6	2	2	0	0	0
108	*Chrysothamnus nauseosus*	2	4	0	4	2	2	0	0	0
111	*Holodiscus discolor*	0	0	0	0	0	0	0	0	0
115	*Lonicera utahensis*	2	4	6	4	2	2	2	4	4
119	*Philadelphus lewisii*	2	2	2	6	2	4	0	0	0
122	*Physocarpus malvaceus*	4	2	4	2	2	4	0	0	0
123	*Prunus emarginata*	4	0	6	0	2	2	2	4	6
124	*Prunus virginiana*	4	4	4	6	2.5	3	2	4	6
125	*Purshia tridentata*	6	6	0	6	4	6	0	0	0
149	*Rhamnus purshiana*	0	0	0	0	0	0	0	0	0
128	*Ribes cereum*	0	2	2	0	2	2.5	2	6	4
131	*Ribes viscosissimum*	0	0	6	0	2	3	2	6	4
133	*Rosa gymnocarpa*	6	4	6	4	2	4	0	0	0
161	*Rosa nutkana*	6	4	6	4	2	4	0	0	0
136	*Rubus parviflorus*	4	2	6	2	2	4	2	4	2
137	*Salix scouleriana*	6	0	0	4	2	3	0	0	0
164	*Sambucus cerulea*	6	2	6	0	3	4	2	2	2
140	*Sorbus scopulina*	6	0	6	4	0	0	2	2	6
142	*Spiraea betulifolia*	4	2	0	4	2	3	0	0	0
143	*Symphoricarpos albus*	4	2	6	6	2	4	2	2	2
163	*Symphoricarpos oreophilus*	4	3	4	0	2	3	2	2	2
146	*Vaccinium globulare*	6	4	6	2	2	4	2	6	4

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[1] Code to constancy values: + = 0 - 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

[2] Palatability ratings are from Kufeld and others (1973), Kufeld (1973), USDA FS (1986), and Beecham (1981).

(con.)

APPENDIX B-1 (Con.)

SHRUB LAYER GROUP		*Ceanothus velutinus*						
Shrub layer type		CEVE -CEVE	CEVE -RICE	CEVE -SASC	CEVE -PREM	CEVE -AMAL	CEVE -SPBE	CEVE -PHMA
Number of stands		*n* = 6	n = 2	*n* = 10	*n* = 2	*n* = 3	*n* = 10	*n* = 15
ADP No.	**Shrub species**							
102	*Acer glabrum*	2(0.5)	5(3.0)	6(10.6)	—	—	2(3.0)	5(6.4)
105	*Amelanchier alnifolia*	8(4.4)	5(3.0)	7(7.8)	5(3.0)	10(30.0)	10(4.1)	9(1.8)
203	*Berberis repens*	5(0.5)	—	1(0.5)	—	10(1.3)	4(1.1)	3(0.5)
198	*Ceanothus sanguineus*	3(73.8)	—	5(19.0)	—	3(37.5)	1(37.5)	2(11.0)
107	*Ceanothus velutinus*	8(54.1)	10(15.0)	8(21.9)	10(15.0)	7(26.3)	10(13.8)	9(21.9)
108	*Chrysothamnus nauseosus*	2(0.5)	5(0.5)	—	5(0.5)	—	—	2(0.5)
111	*Holodiscus discolor*	—	—	—	—	—	—	—
115	*Lonicera utahensis*	—	—	4(1.1)	—	—	—	1(0.5)
119	*Philadelphus lewisii*	—	—	1(3.0)	—	—	—	—
122	*Physocarpus malvaceus*	10(22.5)	10(9.0)	10(24.0)	10(15.0)	10(30.0)	10(22.8)	10(47.5)
123	*Prunus emarginata*	5(3.0)	5(15.0)	3(7.0)	10(26.3)	3(15.0)	6(3.3)	6(10.1)
124	*Prunus virginiana*	2(0.5)	5(0.5)	—	5(15.0)	7(1.8)	2(7.8)	3(4.8)
125	*Purshia tridentata*	—	—	1(0.5)	5(0.5)	10(0.5)	2(3.0)	1(0.5)
149	*Rhamnus purshiana*	—	—	1(0.5)	—	—	1(0.5)	—
128	*Ribes cereum*	—	5(3.0)	1(0.5)	5(3.0)	7(1.8)	2(0.5)	1(0.5)
131	*Ribes viscosissimum*	3(0.5)	10(26.3)	4(0.5)	5(0.5)	—	1(0.5)	3(1.1)
133	*Rosa gymnocarpa*	3(1.8)	—	3(0.5)	—	—	1(0.5)	2(0.5)
161	*Rosa nutkana*	3(0.5)	—	3(1.3)	5(0.5)	3(0.5)	5(1.5)	3(0.5)
136	*Rubus parviflorus*	3(0.5)	—	5(4.9)	—	—	2(0.5)	3(1.1)
137	*Salix scouleriana*	7(3.0)	10(1.8)	10(50.0)	5(0.5)	7(1.8)	7(8.1)	6(7.2)
164	*Sambucus cerulea*	2(15.0)	5(15.0)	—	—	—	2(1.8)	4(0.9)
140	*Sorbus scopulina*	—	—	5(4.9)	—	—	—	2(2.2)
142	*Spiraea betulifolia*	10(15.3)	10(3.0)	10(13.0)	5(3.0)	10(7.0)	10(36.8)	9(5.7)
143	*Symphoricarpos albus*	5(0.5)	—	5(6.3)	—	7(7.8)	2(19.0)	1(9.0)
163	*Symphoricarpos oreophilus*	2(15.0)	10(3.0)	2(1.8)	10(7.8)	10(7.0)	6(1.8)	6(3.2)
146	*Vaccinium globulare*	—	—	3(12.8)	—	—	1(3.0)	1(3.0)

[1] Code to constancy values:

+ = 0- 5%	2 = 15-25%	4 = 35-45%	6 = 55-65%	8 = 75-85%	10 = 95-100%
1 = 5-15%	3 = 25-35%	5 = 45-55%	7 = 65-75%	9 = 85-95%	

(con.)

APPENDIX B-1 (Con.)[1]

SHRUB LAYER GROUP		Ribes cereum			Salix scouleriana				Prunus emarginata			
Shrub layer type		RICE -RICE	RICE -AMAL	RICE -PHMA	SASC -SASC	SASC -AMAL	SASC -SPBE	SASC -PHMA	PREM -PREM	PREM -AMAL	PREM -SPBE	PREM -PHMA
Number of stands		*n* = 2	*n* = 2	*n* = 1	*n* = 3	*n* = 3	*n* = 4	*n* = 17	*n* = 2	*n* = 1	*n* = 1	*n* = 8
ADP No.	Shrub species											
102	*Acer glabrum*	5(0.5)	—	—	7(1.8)	7(0.5)	10(4.8)	4(8.6)	10(1.8)	—	—	4(3.0)
105	*Amelanchier alnifolia*	10(1.8)	10(9.0)	10(0.5)	3(3.0)	10(30.0)	10(1.8)	9(6.3)	10(9.0)	—	10(0.5)	6(9.7)
203	*Berberis repens*	5(0.5)	10(0.5)	10(0.5)	3(0.5)	7(1.8)	—	4(1.2)	10(1.8)	10(15.0)	—	5(0.5)
198	*Ceanothus sanguineus*	—	—	—	—	—	5(3.0)	1(3.0)	—	—	—	3(0.5)
107	*Ceanothus velutinus*	5(3.0)	10(1.8)	10(0.5)	7(1.8)	7(3.0)	5(1.8)	4(2.3)	—	10(3.0)	10(3.0)	4(1.3)
108	*Chrysothamnus nauseosus*	—	—	—	—	—	—	1(0.5)	5(0.5)	—	—	1(0.5)
111	*Holodiscus discolor*	—	—	—	—	—	—	—	—	—	—	—
115	*Lonicera utahensis*	5(0.5)	—	—	3(15.0)	3(3.0)	5(3.0)	1(1.8)	—	—	—	—
119	*Philadelphus lewisii*	—	—	—	—	—	—	1(15.0)	—	—	—	1(3.0)
122	*Physocarpus malvaceus*	10(15.0)	10(15.0)	10(37.5)	10(18.5)	10(15.0)	10(14.6)	10(46.8)	10(26.3)	10(3.0)	10(15.0)	10(46.9)
123	*Prunus emarginata*	10(1.8)	10(0.5)	—	3(0.5)	3(0.5)	5(15.0)	3(17.1)	10(26.3)	—	10(15.0)	9(13.3)
124	*Prunus virginiana*	—	—	—	3(15.0)	—	—	2(5.3)	10(26.3)	10(15.0)	10(3.0)	8(8.6)
125	*Purshia tridentata*	—	—	—	—	3(0.5)	—	1(0.5)	—	—	—	—
149	*Rhamnus purshiana*	—	—	—	—	—	—	—	—	—	—	—
128	*Ribes cereum*	10(26.3)	10(15.0)	—	—	—	3(0.5)	1(0.5)	5(3.0)	10(0.5)	—	—
131	*Ribes viscosissimum*	10(1.8)	5(3.0)	10(15.0)	7(1.8)	3(0.5)	5(1.8)	2(0.5)	5(0.5)	—	—	1(0.5)
133	*Rosa gymnocarpa*	—	—	—	—	3(0.5)	5(0.5)	3(2.5)	—	—	—	1(0.5)
161	*Rosa nutkana*	—	5(0.5)	—	3(0.5)	—	5(0.5)	2(1.1)	—	10(15.0)	10(0.5)	3(0.5)
136	*Rubus parviflorus*	—	—	—	3(0.5)	—	3(62.5)	2(9.0)	—	—	—	—
137	*Salix scouleriana*	10(3.0)	—	10(0.5)	10(45.8)	10(30.0)	10(20.6)	9(19.5)	—	—	10(0.5)	5(2.4)
164	*Sambucus cerulea*	5(3.0)	—	10(0.5)	3(0.5)	—	—	1(0.5)	—	—	—	—
140	*Sorbus scopulina*	—	—	—	—	—	3(0.5)	2(10.2)	—	—	—	3(0.5)
142	*Spiraea betulifolia*	10(1.8)	10(1.8)	10(3.0)	10(10.2)	10(7.0)	10(31.9)	9(11.4)	5(0.5)	10(3.0)	10(15.0)	6(14.2)
143	*Symphoricarpos albus*	—	—	—	—	3(15.0)	—	4(15.4)	—	—	—	—
163	*Symphoricarpos oreophilus*	10(3.0)	10(37.5)	10(3.0)	3(0.5)	7(1.8)	5(1.8)	4(2.9)	10(9.0)	10(37.5)	—	8(7.0)
146	*Vaccinium globulare*	—	—	—	—	7(1.8)	—	1(50.0)	—	—	—	1(3.0)

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[1] Code to constancy values:
+ = 0- 5% 2 = 15-25% 4 = 35-45% 6 = 55-65% 8 = 75-85% 10 = 95-100%
1 = 5-15% 3 = 25-35% 5 = 45-55% 7 = 65-75% 9 = 85-95%

(con.)

APPENDIX B-1 (Con.)[1]

SHRUB LAYER GROUP		*Amelanchier alnifolia*		*Spiraea betulifolia*		*Physocarpus malvaceus*
Shrub layer type		AMAL -SPBE	AMAL -PHMA	SPBE -SPBE	SPBE -PHMA	PHMA -PHMA
Number of stands		*n* = 5	*n* = 10	*n* = 3	n = 20	*n* = 21
ADP No.	Shrub species					
102	*Acer glabrum*	8(1.8)	6(14.8)	3(15.0)	4(12.7)	4(5.4)
105	*Amelanchier alnifolia*	10(16.6)	10(16.0)	10(2.2)	10(1.9)	8(2.2)
203	*Berberis repens*	8(0.5)	4(1.1)	7(31.5)	6(0.9)	4(0.5)
198	*Ceanothus sanguineus*	—	—	—	0(0.5)	—
107	*Ceanothus velutinus*	2(3.0)	3(1.3)	3(0.5)	4(2.2)	3(1.3)
108	*Chrysothamnus nauseosus*	—	—	—	—	0(0.5)
111	*Holodiscus discolor*	—	—	—	1(11.0)	0(3.0)
115	*Lonicera utahensis*	2(0.5)	1(0.5)	3(0.5)	1(0.5)	1(1.8)
119	*Philadelphus lewisii*	—	—	3(3.0)	1(0.5)	1(3.0)
122	*Physocarpus malvaceus*	10(28.5)	10(63.3)	10(15.0)	10(57.1)	10(61.9)
123	*Prunus emarginata*	—	6(1.8)	—	2(1.1)	4(1.1)
124	*Prunus virginiana*	—	3(1.3)	3(0.5)	4(1.6)	3(1.2)
125	*Purshia tridentata*	—	—	—	1(0.5)	0(3.0)
149	*Rhamnus purshiana*	—	—	—	—	—
128	*Ribes cereum*	—	1(3.0)	—	—	0(3.0)
131	*Ribes viscosissimum*	—	—	7(1.8)	—	0(0.5)
133	*Rosa gymnocarpa*	2(0.5)	—	—	4(0.5)	2(2.4)
161	*Rosa nutkana*	2(0.5)	3(0.5)	3(15.0)	2(0.5)	1(0.5)
136	*Rubus parviflorus*	4(0.5)	1(0.5)	3(0.5)	0(0.5)	0(3.0)
137	*Salix scouleriana*	2(0.5)	2(3.0)	—	3(2.2)	2(2.0)
164	*Sambucus cerulea*	—	—	—	—	0(0.5)
140	*Sorbus scopulina*	4(0.5)	—	—	1(0.5)	0(0.5)
142	*Spiraea betulifolia*	10(42.5)	10(17.9)	10(12.8)	9(21.3)	7(1.6)
143	*Symphoricarpos albus*	2(15.0)	1(3.0)	7(37.5)	4(18.8)	4(1.9)
163	*Symphoricarpos oreophilus*	6(6.2)	9(3.5)	3(0.5)	4(2.1)	5(1.9)
146	*Vaccinium globulare*	—	—	—	—	—

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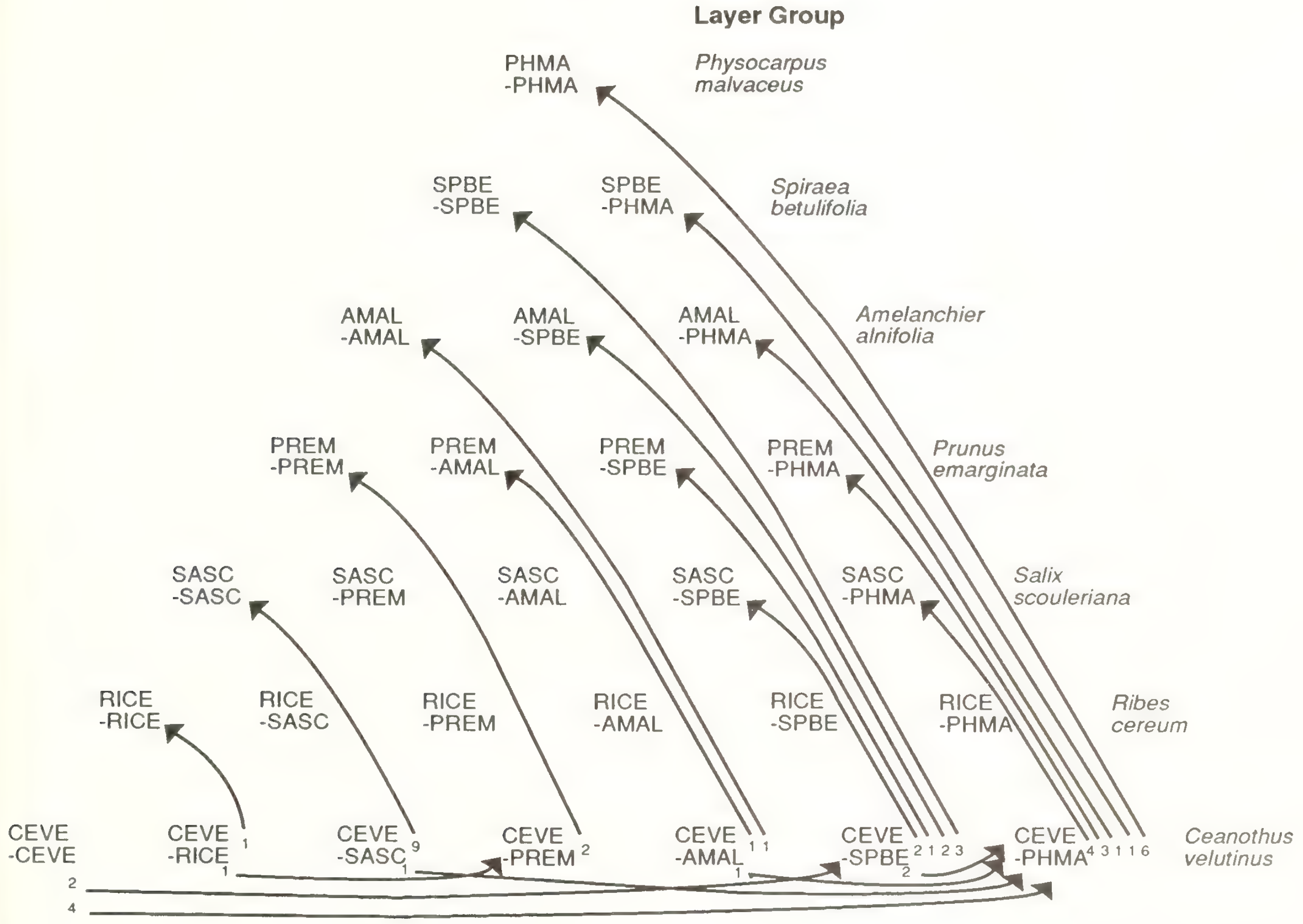
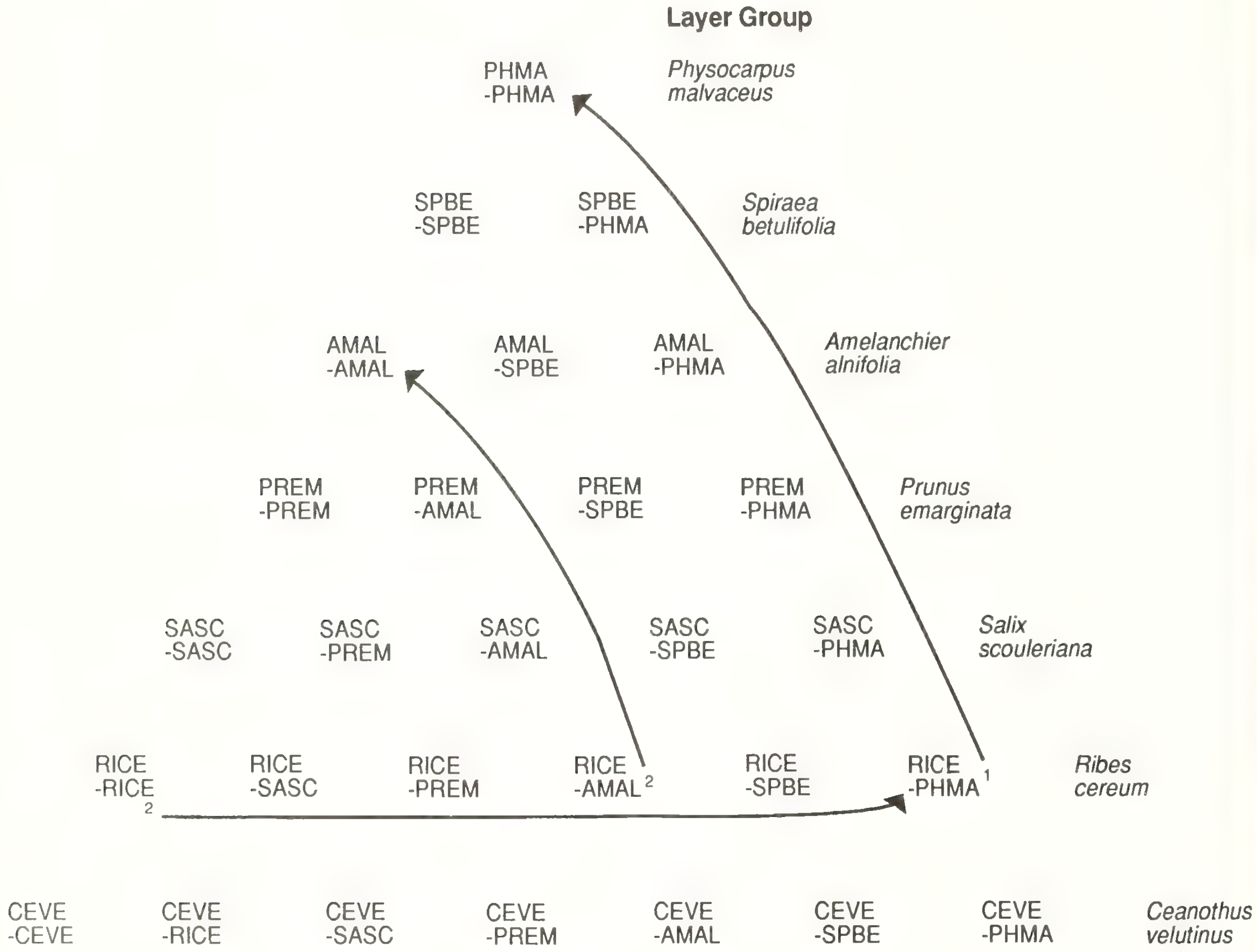
[1] Code to constancy values:
+ = 0-5% 2 = 15-25% 4 = 35-45% 6 = 55-65% 8 = 75-85% 10 = 95-100%
1 = 5-15% 3 = 25-35% 5 = 45-55% 7 = 65-75% 9 = 85-95%

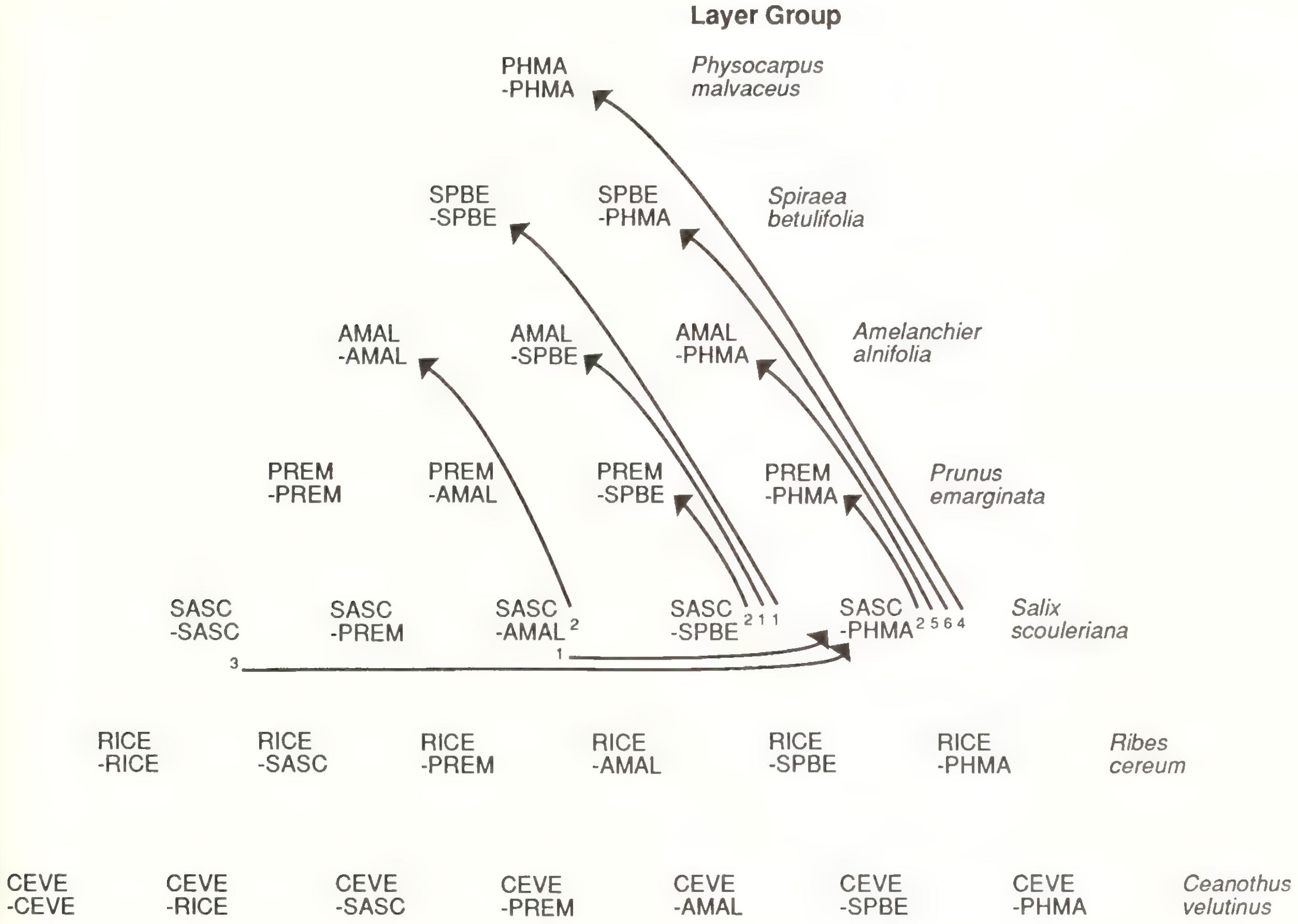
APPENDIX B-2: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE CEVE LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



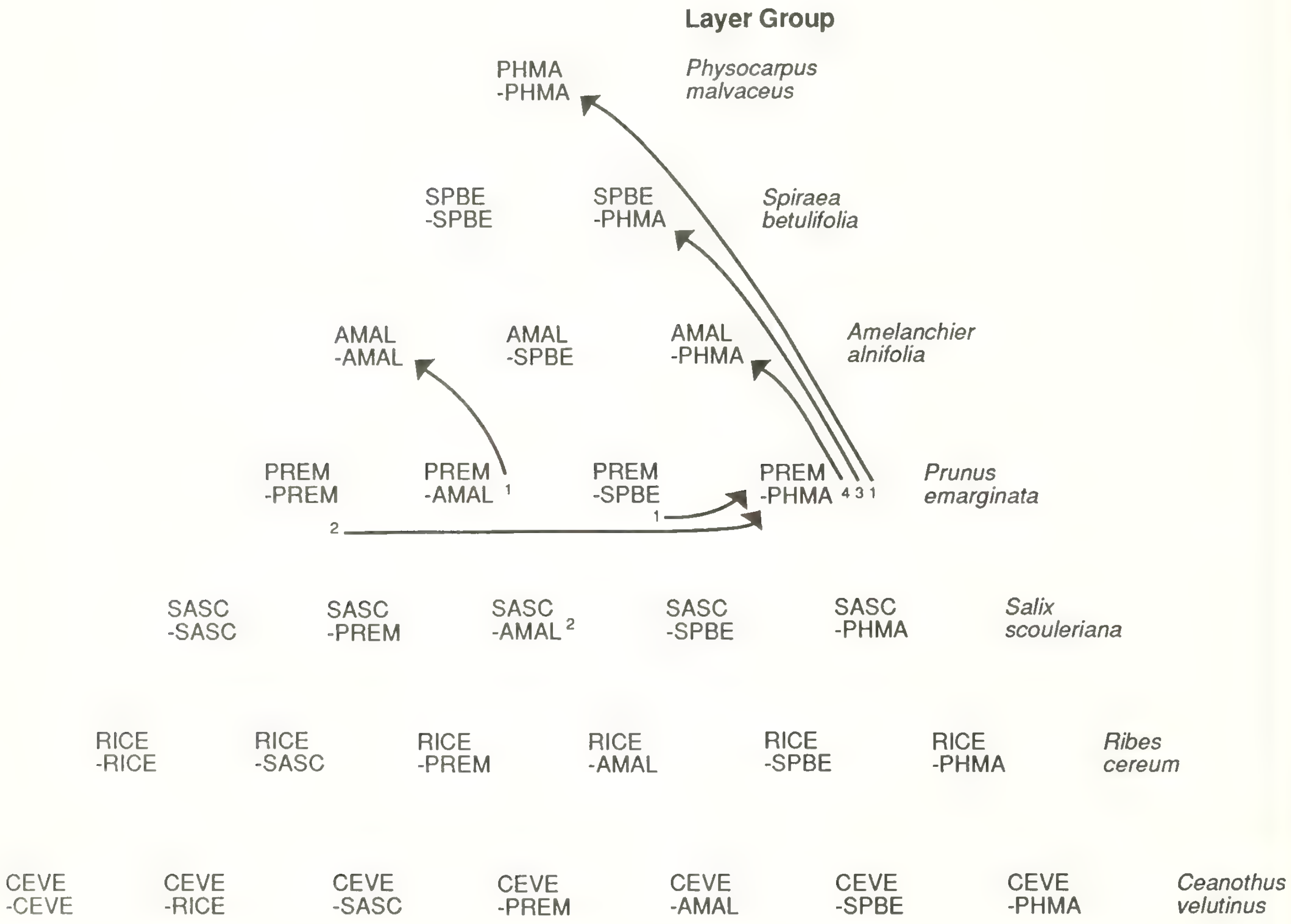
APPENDIX B-3: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE RICE LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



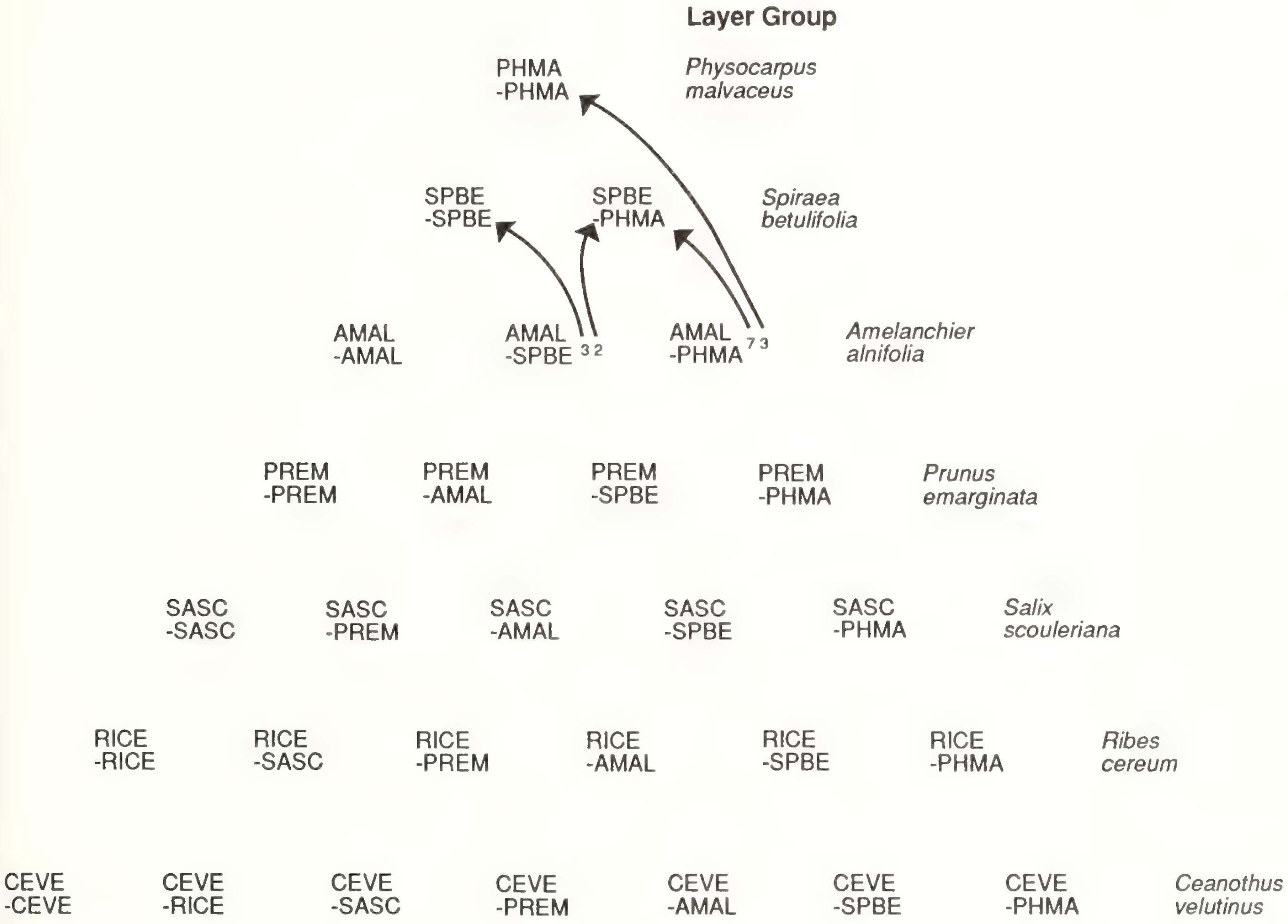
APPENDIX B-4: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE SASC LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



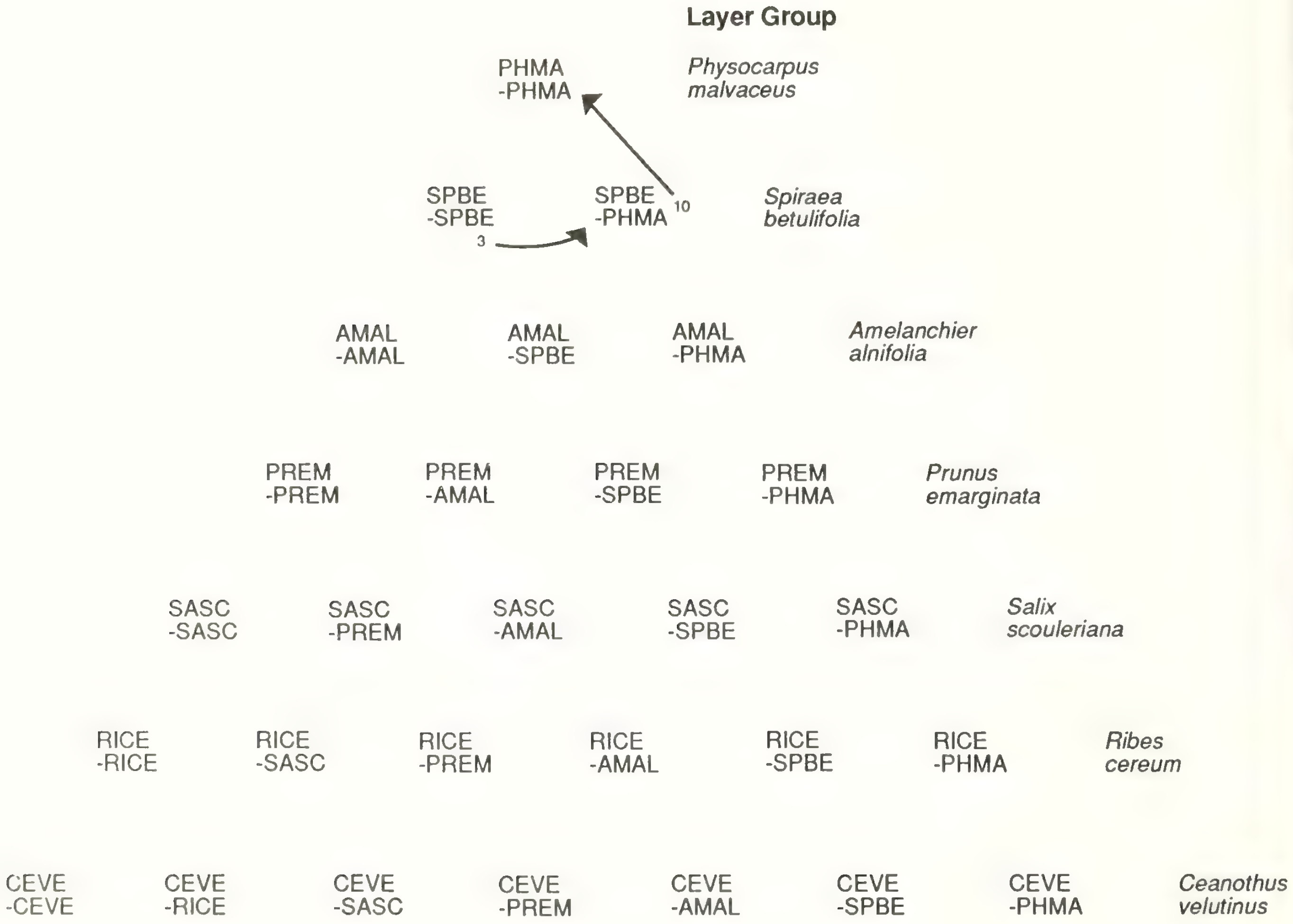
APPENDIX B-5: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE PREM LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



APPENDIX B-6: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE AMAL LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



APPENDIX B-7: SUCCESSIONAL DIRECTION OF SHRUB LAYER TYPES IN THE SPBE LAYER GROUP AS INFERRED FROM INDIVIDUAL PLOT DATA (NUMBERS INDICATE THE NUMBER OF PLOTS INVOLVED)



APPENDIX C: PALATABILITY RATINGS, CONSTANCY,[1] AND AVERAGE CANOPY COVER (PERCENT) OF HERB LAYER SPECIES BY LAYER IN THE PSME/PHMA H.T., PIPO PHASE

HERB LAYER GROUP											Annuals						*Bromus carinatus*	
Herb layer type											ANN. -ANN.	ANN. -BRCA	ANN. -POGL	ANN. -ILRI	ANN. -CAGE	ANN. -CARU	BRCA -BRCA	BRCA -FRVE
Number of stands											*n* = 3	*n* = 2	*n* = 2	*n* = 1	*n* = 1	*n* = 1	*n* = 3	*n* = 1
	Palatability ratings[2]	Deer		Elk				Black bear										
ADP No.	Perennial Graminoids	Summer	Winter	Summer	Winter	Cattle	Sheep	Spring	Summer	Fall								
*18	*Agropyron intermedium*	0	0	0	0	0	0	0	0	0	—	—	—	—	—	—	3(0.5)	—
301	*Agropyron spicatum*	2	4	4	6	4	2	0	0	0	—	—	—	—	—	—	3(37.5)	—
303	*Bromus carinatus*	4	2	6	4	6	4	0	0	0	7(1.8)	10(26.3)	5(0.5)	10(0.5)	—	—	3(0.5)	10(15.0)
282	*Bromus inermis*	4	0	4	0	6	5	0	0	0	—	5(0.5)	5(0.5)	—	10(0.5)	—	10(15.0)	—
307	*Calamagrostis rubescens*	2	4	6	4	6	4	6	4	2	7(0.5)	—	—	—	10(0.5)	—	7(3.0)	—
309	*Carex geyeri*	4	4	6	6	6	4	6	4	2	3(0.5)	10(1.8)	5(0.5)	—	10(15.0)	10(0.5)	7(0.5)	10(0.5)
311	*Carex rossii*	2	2	4	2	2	4	6	4	2	7(0.5)	—	5(0.5)	10(0.5)	—	—	3(0.5)	—
331	*Poa nervosa*	4	2	6	4	4	4	0	0	0	—	5(0.5)	—	—	—	—	—	—
	Perennial Herbs																	
401	*Achillea millefolium*	2	2	2	2	2	4	0	0	0	—	10(0.5)	10(0.5)	—	10(0.5)	—	—	10(0.5)
566	*Agastache urticifolia*	4	0	4	0	4	6	0	0	0	—	5(0.5)	5(15.0)	10(0.5)	—	—	—	—
413	*Antennaria racemosa*	4	0	2	2	0	0	0	0	0	—	—	—	—	—	—	—	—
415	*Apocynum androsaemifolium*	2	0	2	0	2	2	0	0	0	3(0.5)	5(0.5)	5(0.5)	—	10(0.5)	—	—	—
420	*Arenaria macrophylla*	2	0	2	0	2	4	0	0	0	3(0.5)	10(0.5)	—	—	10(0.5)	10(0.5)	3(0.5)	10(0.5)
421	*Arnica cordifolia*	4	0	4	0	2	4	0	0	0	3(3.0)	10(0.5)	—	—	10(3.0)	10(0.5)	3(0.5)	10(0.5)
426	*Aster conspicuus*	2	2	4	2	4	4	0	0	0	10(0.5)	5(0.5)	5(0.5)	10(3.0)	10(3.0)	10(0.5)	3(0.5)	—
586	*Aster perelegans*	4	2	4	2	4	4	0	0	0	—	—	5(0.5)	—	—	—	—	—
431	*Balsamorhiza sagittata*	4	4	2	4	4	6	0	0	0	—	—	—	—	—	—	—	—
736	*Castilleja applegatei*	2	0	2	0	2	2	0	0	0	—	—	—	—	—	—	—	—
438	*Castilleja miniata*	2	0	2	0	2	2	0	0	0	—	5(0.5)	—	—	10(0.5)	—	7(0.5)	—
455	*Disporum trachycarpum*	0	0	0	0	0	0	0	0	0	—	—	—	—	—	—	—	—
459	*Epilobium angustifolium*	4	2	6	2	2	4	0	0	0	7(0.5)	—	5(0.5)	—	10(0.5)	—	3(0.5)	—
467	*Fragaria* spp.	4	4	2	4	2	4	2	6	2	—	—	—	—	10(0.5)	—	—	10(3.0)
471	*Galium triflorum*	2	0	2	0	2	4	4	2	2	3(0.5)	—	—	—	—	10(15.0)	3(0.5)	—
473	*Geranium viscosissimum*	4	2	6	2	2	4	0	0	0	—	5(0.5)	5(0.5)	—	10(3.0)	—	—	—
628	*Hackelia micrantha*	0	0	0	0	0	0	0	0	0	—	5(0.5)	5(3.0)	10(0.5)	—	10(0.5)	—	—
483	*Hieracium albertinum*	4	2	4	2	6	6	0	0	0	—	—	—	—	10(0.5)	—	—	—
484	*Hieracium albiflorum*	4	2	4	2	6	6	0	0	0	3(0.5)	—	—	—	—	—	3(0.5)	—
633	*Hydrophyllum capitatum*	0	0	0	0	0	0	6	4	2	3(0.5)	5(0.5)	—	—	10(0.5)	10(0.5)	—	—
833	*Iliamna rivularis*	4	0	6	0	4	6	0	0	0	3(3.0)	5(15.0)	5(0.5)	10(62.5)	—	—	3(3.0)	—
636	*Lathyrus nevadensis*	4	2	4	2	6	6	0	0	0	—	—	—	—	—	—	—	—
505	*Osmorhiza chilensis*	2	0	2	0	2	4	6	4	2	—	—	—	—	—	10(3.0)	—	10(0.5)
656	*Paeonia brownii*	2	0	2	0	2	2	0	0	0	3(3.0)	—	5(0.5)	—	10(0.5)	—	—	—

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[1] Code to constancy values: + = 0- 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

[2] Based on palatability ratings by Kufeld (1973), Kufeld and others (1973), USDA FS, (1986) and Beecham (1981).

(con.)

APPENDIX C (Con.)[1]

HERB LAYER GROUP											Annuals						*Bromus carinatus*	
Herb layer type											ANN. -ANN.	ANN. -BRCA	ANN. -POGL	ANN. -ILRI	ANN. -CAGE	ANN. -CARU	BRCA -BRCA	BRCA -FRVE
Number of stands											*n* = 3	*n* = 2	*n* = 2	*n* = 1	*n* = 1	*n* = 1	*n* = 3	*n* = 1
	Palatability ratings[2]	Deer		Elk				Black bear										
ADP No.	Perennial herbs	Summer	Winter	Summer	Winter	Cattle	Sheep	Spring	Summer	Fall								
658	*Penstemon attenuatus*	4	2	2	2	2	4	0	0	0	—	—	5(0.5)	—	—	—	—	—
514	*Penstemon wilcoxii*	4	2	2	2	2	4	0	0	0	10(0.5)	—	5(3.0)	10(0.5)	10(0.5)	10(0.5)	7(1.8)	10(15.0)
522	*Potentilla glandulosa*	4	2	4	2	2	4	0	0	0	7(0.5)	10(3.0)	10(9.0)	—	—	—	—	—
675	*Rudbeckia occidentalis*	4	2	2	2	2	4	0	0	0	—	—	5(0.5)	—	—	—	—	—
542	*Smilacina racemosa*	6	2	4	2	2	4	6	4	2	7(0.5)	—	5(0.5)	10(0.5)	10(0.5)	10(0.5)	7(0.5)	10(0.5)
685	*Stellaria jamesiana*	0	0	0	0	0	0	0	0	0	—	—	—	—	—	—	—	—
#47	*Thalictrum* spp.	4	2	6	2	2	4	0	0	0	7(1.8)	10(0.5)	5(0.5)	10(3.0)	10(0.5)	—	3(0.5)	—
*09	*Tragopogon dubius*	4	2	4	4	4	4	0	0	0	3(3.0)	5(0.5)	5(0.5)	—	10(0.5)	—	3(0.5)	10(0.5)
560	*Trillium ovatum*	0	0	0	0	0	0	4	4	2	—	—	5(0.5)	—	—	—	—	—
691	*Veratrum californicum*	4	2	4	2	4	4	2	2	2	3(0.5)	5(0.5)	10(0.5)	10(0.5)	—	—	—	—
	Ferns																	
259	*Pteridium aquilinum*	4	0	2	0	2	4	0	0	0	—	—	—	—	—	—	—	—
	Annuals, biennials, and short-lived perennials																	
417	*Arabis* spp.	2	0	2	0	2	2	0	0	0	3(0.5)	10(0.5)	5(0.5)	—	10(0.5)	—	—	—
*11	*Bromus tectorum*	2	4	2	4	2	2	0	0	0	—	—	—	—	—	—	—	10(3.0)
*12	*Cirsium vulgare*	2	2	2	2	2	2	0	0	0	3(0.5)	—	—	—	—	—	—	10(0.5)
912	*Clarkia rhomboidea*	2	0	2	0	2	2	0	0	0	7(0.5)	—	5(0.5)	—	—	—	3(0.5)	—
902	*Collinsia parviflora*	2	0	2	0	2	2	0	0	0	3(15.0)	5(0.5)	—	—	10(0.5)	10(0.5)	—	—
913	*Collomia grandiflora*	2	0	2	0	2	2	0	0	0	7(0.5)	—	5(0.5)	—	—	—	3(0.5)	—
921	*Collomia tenella*	2	0	2	0	2	2	0	0	0	—	5(0.5)	—	—	—	—	—	—
#54	*Cryptantha* spp.	0	0	0	0	0	2	0	0	0	3(0.5)	5(0.5)	5(0.5)	10(3.0)	—	—	—	—
915	*Descurainia richardsonii*	2	0	2	0	2	2	0	0	0	—	5(0.5)	5(15.0)	10(15.0)	—	10(0.5)	—	10(0.5)
904	*Epilobium* spp.	2	0	2	0	2	2	0	0	0	7(1.8)	5(15.0)	5(15.0)	—	—	—	—	10(3.0)
#55	*Galium* spp.	2	0	2	0	2	2	6	4	2	7(0.5)	10(7.8)	—	10(0.5)	10(0.5)	10(0.5)	—	—
930	*Gayophytum* spp.	2	0	2	0	2	2	0	0	0	3(15.0)	5(0.5)	—	10(0.5)	10(15.0)	—	—	—
886	*Gnaphalium microcephalum*	2	0	2	0	2	4	0	0	0	7(3.0)	—	—	—	—	—	—	—
*02	*Lactuca serriola*	4	2	4	2	6	6	0	0	0	3(37.5)	—	—	—	—	—	—	10(0.5)
#51	*Phacelia* spp.	0	0	0	0	0	0	0	0	0	7(0.5)	5(0.5)	5(0.5)	10(0.5)	10(0.5)	—	—	10(0.5)
*16	*Verbascum thapsus*	2	2	2	2	2	2	0	0	0	—	10(0.5)	10(0.5)	—	—	10(0.5)	—	10(0.5)
999	Bare soil										10(22.5)	10(20.3)	10(26.3)	10(3.0)	10(15.0)	10(0.5)	10(3.0)	10(15.0)
	Years since disturbance -	average:									6	12	6	2	17	11	6	13
		range:									4 - 10	8 - 15	3 - 9	-	-	-	5 -7	-

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[1] Code to constancy values: + = 0- 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

[2] Based on palatability ratings by Kufeld (1973), Kufeld and others (1973), USDA-FS (1986), and Beecham (1981).

(con.)

APPENDIX C (Con.)[1]

HERB LAYER GROUP		*Potentilla glandulosa*			*Iliamna rivularis*	*Epilobium angustifolium*				*Apocynum androsaemifolium*		*Fragaria vesca*		*Carex geyeri*		*Calamagrostis rubescens*		*Thalictrum occidentale*
Herb layer type		POGL -POGL	POGL -EPAN	POGL -FRVE	ILRI -ILRI	EPAN -EPAN	EPAN -APAN	EPAN -CARU	EPAN -THOC	APAN -APAN	APAN -CAGE	FRVE -CAGE	FRVE -CARU	CAGE -CAGE	CAGE -CARU	CARU -CARU	CARU -THOC	THOC -THOC
Number of stands		*n* = 5	*n* = 2	*n* = 1	*n* = 1	*n* = 3	*n* = 1	*n*= 2	*n* = 1	*n* = 2	*n* = 1	*n* = 1	*n* = 3	*n* = 21	*n* = 5	*n* = 25	*n* = 2	*n* = 10
ADP No.	**Perennial graminoids**																	
*18	*Agropyron intermedium*	—	—	—	—	3(3.0)	—	—	—	—	—	—	—	—	—	—	—	—
301	*Agropyron spicatum*	—	—	—	—	3(0.5)	—	—	—	—	10(3.0)	—	—	1(1.3)	—	—	—	—
303	*Bromus carinatus*	6(1.3)	10(0.5)	10(0.5)	—	—	—	—	—	5(0.5)	—	—	—	2(0.5)	2(0.5)	0(0.5)	5(3.0)	2(0.5)
282	*Bromus inermis*	—	—	—	—	3(0.5)	—	—	10(0.5)	—	—	10(0.5)	—	—	—	—	—	1(0.5)
307	*Calamagrostis rubescens*	4(0.5)	—	—	10(3.0)	7(3.0)	10(3.0)	10(7.8)	—	—	10(0.5)	10(15.0)	10(22.5)	4(3.6)	10(7.3)	8(21.5)	5(0.5)	5(0.5)
309	*Carex geyeri*	8(1.1)	5(3.0)	—	10(0.5)	3(0.5)	10(0.5)	10(1.8)	—	10(1.8)	10(15.0)	10(3.0)	7(0.5)	10(24.3)	10(12.1)	6(1.2)	—	6(0.9)
311	*Carex rossii*	4(0.5)	—	10(0.5)	10(0.5)	7(0.5)	—	5(0.5)	10(0.5)	—	—	10(0.5)	3(0.5)	2(0.5)	4(0.5)	1(0.5)	5(0.5)	1(0.5)
331	*Poa nervosa*	—	—	—	—	3(0.5)	—	—	—	—	—	—	3(3.0)	2(0.5)	—	1(0.5)	—	—
	Perennial herbs																	
401	*Achillea millefolium*	6(0.5)	5(0.5)	10(0.5)	10(0.5)	—	—	—	—	5(0.5)	—	10(0.5)	10(0.5)	3(0.5)	2(0.5)	3(0.5)	—	—
566	*Agastache urticifolia*	4(15.0)	—	—	—	—	—	—	—	—	10(3.0)	—	—	0(0.5)	—	0(0.5)	—	1(0.5)
413	*Antennaria racemosa*	—	—	—	—	—	—	—	—	—	—	10(0.5)	—	0(0.5)	—	2(11.9)	—	—
415	*Apocynum androsaemifolium*	—	5(15.0)	10(0.5)	—	3(0.5)	10(3.0)	—	—	10(15.0)	—	—	3(0.5)	2(0.5)	—	2(1.1)	—	1(0.5)
420	*Arenaria macrophylla*	4(0.5)	5(0.5)	—	—	—	10(0.5)	5(0.5)	—	—	—	10(0.5)	3(0.5)	8(0.8)	10(0.5)	7(1.1)	—	5(1.0)
421	*Arnica cordifolia*	4(1.8)	—	—	10(0.5)	7(1.8)	—	10(9.0)	—	—	—	10(0.5)	3(62.5)	7(2.5)	10(9.2)	8(10.6)	10(15.0)	2(1.8)
426	*Aster conspicuus*	2(0.5)	5(15.0)	10(0.5)	—	3(3.0)	—	—	10(0.5)	—	—	10(15.0)	7(0.5)	3(2.6)	2(15.0)	6(1.3)	—	6(0.9)
586	*Aster perelegans*	2(0.5)	—	—	—	3(0.5)	—	—	—	5(0.5)	—	—	—	1(1.3)	—	1(0.5)	—	—
431	*Balsamorhiza sagittata*	4(0.5)	—	—	10(0.5)	7(7.8)	—	—	—	5(3.0)	10(3.0)	—	—	4(0.5)	2(0.5)	0(0.5)	—	1(0.5)
736	*Castilleja applegatei*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1(0.5)	—	—
438	*Castilleja miniata*	—	—	—	—	—	—	10(7.8)	10(3.0)	—	—	10(0.5)	3(0.5)	2(0.5)	—	2(1.1)	—	—
455	*Disporum trachycarpum*	—	—	—	—	—	—	—	—	—	—	—	—	1(0.5)	—	2(1.0)	—	1(0.5)
459	*Epilobium angustifolium*	2(0.5)	5(0.5)	—	—	3(15.0)	10(15.0)	5(15.0)	10(15.0)	—	—	—	7(0.5)	2(0.5)	2(0.5)	4(0.5)	10(0.5)	8(0.8)
467	*Fragaria* spp.	—	—	10(62.5)	—	3(3.0)	10(3.0)	5(0.5)	10(0.5)	5(0.5)	—	10(15.0)	10(22.5)	4(1.1)	8(1.1)	5(1.3)	—	3(0.5)
471	*Galium triflorum*	—	—	—	—	—	—	5(0.5)	—	—	—	—	—	—	6(0.5)	3(2.6)	10(1.8)	4(0.5)
473	*Geranium viscosissimum*	4(1.8)	10(7.8)	—	—	3(15.0)	10(0.5)	—	10(0.5)	5(0.5)	10(0.5)	10(3.0)	3(0.5)	2(0.5)	—	1(0.5)	—	1(0.5)
628	*Hackelia micrantha*	6(1.3)	—	—	—	—	—	—	—	—	10(0.5)	—	—	—	—	—	—	1(0.5)
483	*Hieracium albertinum*	—	—	—	—	3(3.0)	—	—	—	—	—	—	—	4(0.5)	2(0.5)	2(0.5)	—	2(0.5)
484	*Hieracium albiflorum*	2(0.5)	—	—	—	—	10(0.5)	5(0.5)	—	—	—	10(0.5)	3(0.5)	2(0.5)	6(0.5)	4(0.5)	5(0.5)	2(0.5)
633	*Hydrophyllum capitatum*	6(0.5)	5(0.5)	—	—	—	—	—	—	5(0.5)	10(0.5)	—	—	0(0.5)	4(0.5)	1(0.5)	—	1(3.0)
833	*Iliamna rivularis*	2(0.5)	—	10(0.5)	10(15.0)	3(0.5)	10(0.5)	—	—	—	—	—	—	0(3.0)	—	—	—	—
636	*Lathyrus nevadensis*	2(0.5)	—	—	—	—	—	—	—	5(3.0)	—	—	3(0.5)	0(3.0)	2(0.5)	1(6.2)	—	1(15.0)
505	*Osmorhiza chilensis*	—	—	—	—	3(0.5)	—	—	—	5(0.5)	—	—	3(0.5)	0(0.5)	4(1.8)	3(0.5)	5(0.5)	4(0.5)
656	*Paeonia brownii*	4(0.5)	5(0.5)	—	—	—	—	—	—	—	—	—	—	0(0.5)	4(0.5)	1(0.5)	—	1(0.5)

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[1] Code to constancy values. + = 0- 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

(con)

APPENDIX C (Con.)[1]

HERB LAYER GROUP		*Potentilla glandulosa*			*Iliamna rivularis*		*Epilobium angustifolium*			*Apocynum androsaemifolium*		*Fragaria vesca*		*Carex geyeri*		*Calamagrostis rubescens*		*Thalictrum occidentale*
Herb layer type		POGL -POGL	POGL -EPAN	POGL -FRVE	ILRI -ILRI	EPAN -EPAN	EPAN -APAN	EPAN -CARU	EPAN -THOC	APAN -APAN	APAN -CAGE	FRVE -FRVE	FRVE -CARU	CAGE -CAGE	CAGE -CARU	CARU -CARU	CARU -THOC	THOC -THOC
Number of stands		*n* = 5	*n* = 2	*n* = 1	*n* = 1	*n* = 3	*n* = 1	*n* = 2	*n* = 1	*n* = 2	*n* = 1	*n* = 1	*n* = 3	*n* = 21	*n* = 5	*n* = 25	*n* = 2	*n* = 10
ADP No.	**Perennial herbs**																	
658	*Penstemon attenuatus*	—	5(15.0)	—	10(0.5)	—	—	—	—	—	—	—	—	1(0.5)	—	0(0.5)	—	—
514	*Penstemon wilcoxii*	6(0.5)	5(0.5)	10(3.0)	—	7(0.5)	10(0.5)	—	—	—	—	10(0.5)	7(0.5)	4(0.5)	6(0.5)	3(0.5)	5(0.5)	6(0.5)
522	*Potentilla glandulosa*	10(17.1)	10(15.0)	10(0.5)	—	3(0.5)	—	5(0.5)	10(0.5)	5(0.5)	10(0.5)	10(0.5)	3(0.5)	5(0.5)	—	1(1.3)	—	4(0.5)
675	*Rudbeckia occidentalis*	2(0.5)	—	10(37.5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
542	*Smilacina racemosa*	6(0.5)	5(0.5)	—	—	—	—	10(0.5)	—	—	—	—	7(0.5)	7(0.5)	8(0.5)	5(1.1)	10(0.5)	6(0.9)
685	*Stellaria jamesiana*	—	—	—	—	—	—	—	—	—	—	—	—	2(0.5)	2(0.5)	0(0.5)	—	2(0.5)
#47	*Thalictrum* spp.	6(0.5)	5(0.5)	—	—	—	—	10(3.0)	10(15.0)	—	—	10(0.5)	3(3.0)	3(0.5)	6(1.3)	4(2.7)	10(15.0)	9(17.5)
*09	*Tragopogon dubius*	—	—	—	—	7(0.5)	—	—	—	—	—	10(0.5)	—	1(0.5)	—	1(0.5)	—	1(0.5)
560	*Trillium ovatum*	—	—	—	—	—	—	—	—	—	—	—	3(3.0)	—	—	2(0.5)	5(0.5)	1(0.5)
691	*Veratrum californicum*	2(3.0)	5(0.5)	—	—	—	—	—	—	—	10(15.0)	—	3(0.5)	—	4(0.5)	1(0.5)	5(0.5)	3(0.5)
	Ferns																	
259	*Pteridium aquilinum*	—	—	—	—	—	10(15.0)	—	—	—	—	—	—	0(0.5)	2(0.5)	1(3.0)	5(0.5)	1(0.5)
	Annuals, biennials, and short-lived perennials																	
417	*Arabis* spp.	6(0.5)	—	—	—	3(0.5)	—	—	10(0.5)	5(0.5)	10(0.5)	—	—	1(0.5)	—	0(0.5)	—	—
*11	*Bromus tectorum*	—	—	—	—	—	—	—	—	5(0.5)	—	—	—	0(0.5)	—	0(0.5)	—	—
*12	*Cirsium vulgare*	—	—	10(0.5)	—	—	—	—	—	—	—	—	—	—	—	0(0.5)	—	—
912	*Clarkia rhomboidea*	2(0.5)	—	—	—	3(0.5)	—	—	—	—	—	—	—	1(0.5)	—	2(0.5)	—	—
902	*Collinsia parviflora*	8(2.4)	—	—	—	—	—	—	—	—	10(0.5)	—	—	1(0.5)	2(0.5)	2(0.5)	—	—
913	*Collomia grandiflora*	—	5(0.5)	—	—	—	—	—	—	—	—	—	—	1(0.5)	—	1(1.3)	—	—
921	*Collomia tenella*	—	—	—	—	—	10(0.5)	—	—	5(0.5)	—	—	—	1(0.5)	—	0(0.5)	—	—
#54	*Cryptantha* spp.	4(0.5)	—	—	—	3(0.5)	—	—	—	—	—	—	—	1(0.5)	—	0(0.5)	—	1(0.5)
915	*Descurainia richardsonii*	2(0.5)	—	10(0.5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
904	*Epilobium* spp.	—	5(0.5)	10(0.5)	—	3(0.5)	—	—	—	—	—	—	—	1(0.5)	—	1(0.5)	—	—
#55	*Galium* spp.	8(1.1)	—	—	—	—	—	—	—	—	—	—	—	1(0.5)	—	2(1.1)	—	—
930	*Gayophytum* spp.	2(0.5)	5(3.0)	10(0.5)	—	7(3.0)	10(0.5)	—	—	—	—	—	—	—	—	—	—	1(0.5)
886	*Gnaphalium microcephalum*	—	—	—	—	7(0.5)	—	—	—	5(0.5)	—	—	—	0(0.5)	—	—	—	—
*02	*Lactuca serriola*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0(0.5)	—	—
#51	*Phacelia* spp.	6(0.5)	—	—	—	10(0.5)	—	—	10(0.5)	5(0.5)	—	—	—	1(0.5)	—	—	—	1(0.5)
*16	*Verbascum thapsus*	—	—	10(0.5)	—	—	—	—	—	—	—	—	—	0(0.5)	—	—	—	—
999	Bare soil	10(17.1)	10(26.3)	10(15.0)	10(62.5)	10(15.0)	10(0.5)	5(15.0)	10(3.0)	10(7.8)	10(15.0)	10(3.0)	7(3.0)	6(4.8)	2(0.5)	3(17.1)	10(0.5)	1(3.0)
Years since disturbance	- average:	8	13	9	5	17	15	34	8	18	50	10	19	52	54	66	25	60
	- range:	5 - 13	8 - 18	-	-	6 - 37	-	13 - 55	-	-	-	-	10 - 18	8 - 125	8 - 100	10 - 146	10 - 40	4 - 100

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[1] Code to constancy values: + = 0- 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

APPENDIX D: SUCCESSION CLASSIFICATION FIELD FORM FOR THE DOUGLAS-FIR/NINEBARK H.T.

(Code Descriptions)

Livestock Effects:
1-Light Cattle Use
(palatable species stable)
2-Heavy Cattle Use
(palatable species declining)
3-Light Sheep Use
4-Heavy Sheep Use
5-Trampling
(soil surface exposed)
6-None
7-Other—

Fire Effects:
1-Stand Destroyed
2-Stand Partially Destroyed
3-Creeping Ground Fire
4-Hot Broadcast Burn
(soil exposed by fire)
5-Cool Broadcast Burn
(soil not exposed)
6-Burned Slash Piles
7-None
8-Other—

Scarification Effects:
1-Heavy
(soil well churned)
2-Light
(only duff removed)
3-Soil Scraped Away
(by dozer blade)
4-Soil in Piles >18"
(from dozer)
5-None
6-Other—

Name:
Plot No.:
Location:
Date:
Livestock effects:
Fire effects:
-Age
Scarification effects:
-Age

Vegetation Coverage Class:
0-None
T-Rare to 1%
1-1 to 5%
2-5 to 25%
3-25 to 50%
4-50 to 75%
5-75 to 95%
6-95 to 100%

TREES - canopy coverage		o.g.	m.	p.	s.
Rate coverage by d.b.h. classes:		>18"	18-12"	12-4"	4-.1"
ADP					
001	*Abies grandis*				
002	*Abies lasiocarpa*				
010	*Pinus contorta*				
013	*Pinus ponderosa*				
014	*Populus tremuloides*				
016	*Pseudotsuga menziesii*				

SHRUBS - canopy coverage		
ADP		
102	*Acer glabrum*	
105	*Amelanchier alnifolia*	
107	*Ceanothus velutinus*	
198	*Ceanothus sanguineus*	
119	*Philadelphus lewisii*	
122	*Physocarpus malvaceus*	
123	*Prunus emarginata*	
124	*Prunus virginiana*	
128	*Ribes cereum*	
131	*Ribes viscosissimum*	
136	*Rubus parviflorus*	
137	*Salix scouleriana*	
142	*Spiraea* sp.	
143	*Symphoricarpos albus*	
163	*Symphoricarpos oreophilus*	
146	*Vaccinium globulare*	

PERENNIAL GRAMINOIDS		
ADP		
301	*Agropyron spicatum*	
303	*Bromus carinatus*	
282	*Bromus inermis*	
307	*Calamagrostis rubescens*	
309	*Carex geyeri*	
311	*Carex rossii*	
331	*Poa nervosa*	

PERENNIAL HERBS and FERNS		
ADP		
566	*Agastache urticifolia*	
415	*Apocynum androsaemifolium*	
421	*Arnica cordifolia*	
426	*Aster conspicuus*	
421	*Balsamorhiza sagittata*	
#15	*Castilleja* spp.	
459	*Epilobium angustifolium*	
465	*Fragaria vesca*	
466	*Fragaria virginiana*	
470	*Galium triflorum*	
473	*Geranium viscosissimum*	
833	*Iliamna rivularis*	
636	*Lathyrus nevadensis*	
499	*Lupinus* spp.	
658	*Penstemon attenuatus*	
514	*Penstemon wilcoxii*	
522	*Potentilla glandulosa*	
529	*Pteridium aquilinum*	
547	*Thalictrum occidentale*	
691	*Veratrum californicum*	

ANNUALS, BIENNIALS, and SHORT-LIVED PERENNIALS		
ADP		
*11	*Bromus tectorum*	
*12	*Cirsium vulgare*	
#56	*Collomia* spp.	
914	*Cryptantha* spp.	
915	*Descurainia* spp.	
904	*Epilobium* spp.	
*55	*Galium* spp.	
930	*Gayophytum* spp.	
886	*Gnaphalium* spp.	
*02	*Lactuca serriola*	
663	*Phacelia hastata*	
911	*Polygonum douglasii*	
*16	*Verbascum thapsus*	
999	Bare soil	

TREE LAYER TYPE	
SHRUB LAYER TYPE	
HERB LAYER TYPE	

Steele, Robert; Geier-Hayes, Kathleen. 1989. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-252. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Presents a taxonomic system for classifying plant succession in the Douglas-fir/ninebark habitat type in central Idaho. A total of six potential tree layer types, 28 shrub layer types, and 55 herbaceous layer types are categorized. Diagnostic keys based on indicator species provide for field identification of the types. Discussion of management implications includes pocket gopher populations, success of planted and natural tree seedlings, big-game and livestock forage preferences, and responses of major shrub and herb layer species to disturbance.

KEYWORDS: forest succession, plant communities, forest ecology, forest management, silviculture, classification, Idaho

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Silvics of Whitebark Pine (*Pinus albicaulis*)

**Stephen F. Arno
Raymond J. Hoff**

THE AUTHORS

STEPHEN F. ARNO is a research forester for the Prescribed Fire and Fire Effects research work unit at the Intermountain Research Station's Fire Sciences Laboratory, Missoula, MT. He received a B.S. degree in forestry from Washington State University and Masters and Ph.D. degrees from the University of Montana. He has studied various aspects of forest ecology, including subalpine tree species, since 1963.

RAYMOND J. HOFF is principal plant geneticist with the Intermountain Station's Forestry Sciences Laboratory in Moscow, ID. He received a B.A. degree in biology from Western Washington State University and a Ph.D. degree in botany from Washington State University. His main area of work has been with pest resistance in conifers with particular emphasis on blister rust resistance in western white pine.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

Silvics of Whitebark Pine (*Pinus albicaulis*)

Stephen F. Arno
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INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) is a slow-growing, long-lived tree of the high mountains of southwestern Canada and the Western United States. Whitebark pine is of limited commercial use, but it is valued for watershed protection and esthetics. Its seed crops have become recognized in recent years as an important food source for grizzly bears and other wildlife of the high mountains.

Concern has arisen because in some areas whitebark pine cone crops have diminished as a result of successional replacement and insect and disease epidemics (Arno 1986). Published information on whitebark pine has been sparse. This paper is a review of the literature available in 1981 and has been updated to include some recent ecological findings.

HABITAT

Native Range

Whitebark pine (fig. 1) grows in the highest elevation forest and at timberline. Its distribution is essentially split into two broad sections, one following the British Columbia Coast Ranges, the Cascade Range, and the Sierra Nevada, and the other covering the Rocky Mountains from Wyoming to Alberta.

Whitebark pine is abundant and vigorous on the drier, inland slope of the Coast and Cascade Ranges. It is entirely absent from some of the wettest areas, such as the mountains of Vancouver Island. In the Olympic Mountains, it is confined to peaks in the northeastern rain shadow zone. Whitebark pine also occurs atop the highest peaks of the Klamath Mountains of northwestern California.

The Rocky Mountain distribution extends along the high ranges in eastern British Columbia and western Alberta, and southward at high elevations to the Wind River and Salt River Ranges in west-central Wyoming.

A small outlying population of whitebark pine is found atop the Sweetgrass Hills in north-central Montana 90 miles (145 km) east of the nearest stands in the Rocky Mountains across the Great Plains grassland (Thompson and Kuijt 1976).

The coastal and Rocky Mountain distributions lie only 62 miles (100 km) apart at their closest proximily. Even this narrow gap is not absolute; small groves are found on a few isolated peaks in between in northeastern Washington. In addition to the main distribution, whitebark pine grows in the Blue and Wallowa Mountains of northeastern Oregon and in several isolated ranges rising out of the sagebrush steppe in northeastern California, south-central Oregon, and northern Nevada.

Climate

Whitebark pine grows in a cold, windy, snowy, and generally moist climatic zone. In moist mountain ranges, whitebark pine is most abundant on warm, dry exposures. Conversely, in semiarid ranges, it becomes prevalent on

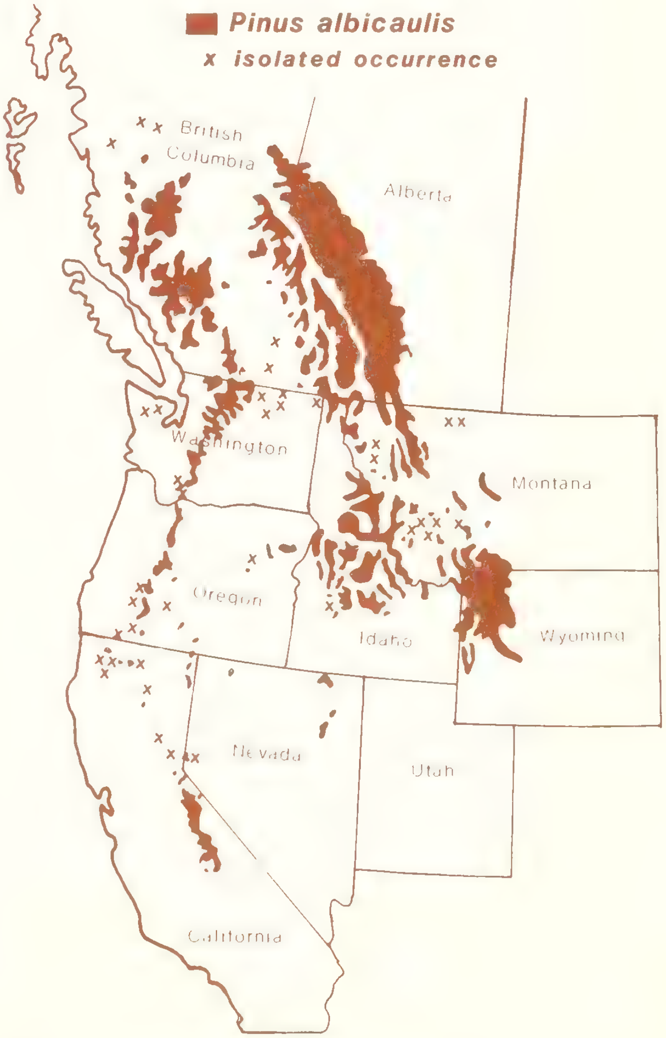

Figure 1—Natural distribution of whitebark pine.

cool exposures and moist sites. Weather data from several whitebark pine sites in the Inland Northwest suggest the climatic interpretations that follow (Arno 1970; Weaver and Dale 1974). Summers are short and cool with mean July temperatures ranging from 55 to 59 °F (13 to 15 °C) in the whitebark pine forest and from 50 to 54 °F (10 to 12 °C) in the adjacent timberline zone. A cool growing season, as defined by mean temperatures of over 42 °F (5.5 °C) (Baker 1944), lasts about 90 to 110 days in the whitebark pine forest, but light frosts and snowfalls sometimes occur even in midsummer. The hottest summer days reach temperatures of 79 to 86 °F (26 to 30 °C). January mean temperatures range from about 15 °F (–9 °C) in Montana to about 23 °F (–5 °C) in the Cascades and Sierra Nevada. Long-term record low temperatures in Montana and Wyoming stands are probably –40 to –58 °F (–40 to –50 °C).

Mean annual precipitation for most stands where whitebark pine is a major component probably is between 24 and 72 inches (600 and 1,800 mm). The lower part of this precipitation range applies to mountain ranges in semiarid regions where whitebark pine forms nearly pure stands or is accompanied only by lodgepole pine (*Pinus contorta* var. *latifolia*). The highest precipitation occurs in inland-maritime ranges and near the Cascade crest where whitebark pine grows primarily with subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*).

About two-thirds of the precipitation in most stands is snow and sleet, with rain prevailing only from June through September (Arno 1970). Summer rainfall is often scant in the southern part of whitebark pine's distribution south of about 47 °N. latitude. Thus, there is often a droughty period with scant rainfall or remaining snowmelt water for several weeks during mid-to-late summer.

Snowpack usually begins to accumulate in late October. By April, the snowpack reaches a maximum depth, ranging from about 24 to 50 inches (60 to 125 cm) in stands east of the Continental Divide and in other semiarid areas, to 100 to 120 inches (250 to 300 cm) in the relatively moist whitebark pine-subalpine fir stands of the Cascades and inland-maritime mountains. Most stands probably have mean annual snowfalls between 180 and 500 inches (460 and 1,270 cm). Whitebark pine also grows in stunted or krummholz (shrublike) form on windswept ridgetops where little snow accumulates.

Strong winds, thunderstorms, and severe blizzards are common to whitebark pine habitats. Wind gusts of hurricane velocity in the tree crowns (more than 73 mi/h or 117 km/h) occur each year on most sites, but most frequently on ridgetops.

Soils and Topography

Most whitebark pine stands grow on weakly developed (immature) soils. Many of the sites were covered by extensive mountain glaciers during the Pleistocene and have been released from glacial ice for less than 12,000 years (Mehringer and others 1977). Chemical weathering is retarded by the short, cool summer season. Also, nitrogen-fixing and other microbiotic activity that might enrich the soil is apparently restricted by low soil temperatures and high acidity on many sites.

Despite these general trends, substantial variations occur in local climates, geologic substrates, and degrees of soil development in whitebark pine habitats. Thus, several types of soils have been recognized.

Most soils under whitebark pine stands are classified as Inceptisols (USDA SCS 1975). Many of these are Typic Cryochrepts, although deposits of volcanic ash may be sufficiently thick in some profiles to warrant recognition as Andic Cryochrepts. Some of the best-developed, ash-layered soils beneath spruce-fir-whitebark pine stands are Typic Cryandepts similar to the zonal Brown Podzolic soils (Nimlos 1963). All of these are young soils, showing less leaching, weathering, and horizon development than Spodosols, although they are quite acidic. Mean pH values of 4.8 to 5.0 were found for the upper mineral soil horizons in three habitat types, probably composed largely of Typic Cryochrepts (Pfister and others 1977). Data on nutrient availability in these soils have been provided (Weaver and Dale 1974).

Throughout its distribution, whitebark pine is often found on soils lacking fine material. Sparse, open stands often grow on coarse talus, exposed bedrock, or lava flows having minimal horizon development and only scattered pockets of fine material. These soils would be classified as fragmental and loamy skeletal families within the order Entisols (Cryorthents in granitic substrates). They have been referred to as azonal soils, and more specifically as Lithosols in earlier classifications.

Some dry-site whitebark pine stands in semiarid regions have open, grassy understories, particularly on calcareous rock substrates. The soils have a thick, dark surface horizon and a nearly neutral reaction. The pH is near 6 in Montana (Pfister and others 1977) and Idaho (Steele and others 1983) stands, but in Alberta average values are 7.8 to 8 (Baig 1972). These soils would evidently be classified as Typic Cryoborolls within the order Mollisols. Also, in some of the same areas soils that have a dark surface but a low level of base saturation are classified as Typic Cryumbrepts.

In all but the driest regions, whitebark pine is most abundant on warm aspects and ridgetops having direct exposure to sun and wind. It is less abundant on sheltered north-facing slopes or in cirque basins, where subalpine fir, Engelmann spruce (*Picea engelmannii*), mountain hemlock, or subalpine larch (*Larix lyallii*) become prevalent. Nevertheless, the tallest and best formed whitebark pine trees are often found in high basins or on gentle north slopes.

Near the northern end of its distribution in the British Columbia coastal mountains, whitebark pine is a minor component of timberline communities at about 5,200 ft (1,580 m) elevation (McAvoy 1931). In the Olympic Mountains and on the western slope of the Cascades in Washington and northern Oregon, it grows primarily on exposed sites near tree line between 5,800 and 7,000 ft (1,170 and 2,130 m). East of the Cascade crest it becomes abundant within both the subalpine forest and the timberline zone. For instance, it is common between 5,300 and 8,000 ft (1,620 and 2,440 m) in central Washington's Stuart Range, generally forming krummholz above 7,000 ft (2,130 m) (Arno and Hammerly 1984). The lowest reported natural stand of whitebark pine throughout its range is at 3,600 ft (1,100 m) near Government Camp on the southwest slope of Mount Hood in Oregon (Franklin 1966).

Whitebark pine becomes a major component of high-elevation forests in the Cascades of southern Oregon and northern California, growing between 8,000 and 9,500 ft (2,440 and 2,900 m) on Mount Shasta. In the central and southern Sierra Nevada it is found between 10,000 and 11,500 ft (3,050 and 3,510 m), but occasionally reaches 12,000 ft (3,660 m) as krummholz cushions (Arno and Hammerly 1984).

Near the north end of its distribution in the Rockies of Alberta and British Columbia, whitebark pine is generally small, scattered, and confined to dry, exposed sites at timberline, 6,500 to 7,500 ft (1,980 to 2,290 m). It becomes increasingly abundant southward, especially in Montana and central Idaho. It is a major component of high-elevation forests and the timberline zone between about 5,900 and 8,200 ft (1,800 and 2,500 m) in northwestern Montana and 7,000 and 9,300 ft (2,130 and 2,830 m) in west-central Montana. In western Wyoming, it is abundant at 8,000 to 10,500 ft (2,440 to 3,200 m).

Associated Forest Cover

Whitebark pine is most frequently found growing with other high mountain conifers, although pure whitebark pine stands are common in relatively dry mountain ranges. The forest cover type Whitebark Pine (Society of American Foresters Type 208) (Society of American Foresters 1980) is used to designate pure stands or mixed stands in which the species comprises a plurality. Whitebark pine is also a minor component of Engelmann Spruce-Subalpine Fir (Type 206) in the Rockies, eastern Cascades, and the Blue Mountains; Mountain Hemlock (Type 205) in much of the Cascades and British Columbia coastal mountains; and California Mixed Subalpine (Type 256) in the California Cascades, Sierra Nevada, and Klamath Mountains. In these open, upper subalpine forests, whitebark pine is associated with mountain hemlock, California and Shasta red fir (*Abies magnifica* vars. *magnifica* and *shastensis*), Sierra lodgepole pine (*Pinus contorta* var. *murrayana*), western white pine (*P. monticola*), and locally, foxtail (*P. balfouriana*) and limber (*P. flexilis*) pines.

In the drier ranges of the Rockies south of latitude 47 ° N. and in south-central Oregon, whitebark pine is found within the highest elevations of the cover type Lodgepole Pine (Type 218). In the Rockies whitebark pine adjoins Interior Douglas-fir (Type 210) and Limber Pine (Type 219). In the East Humboldt, Ruby, Jarbidge, and Bull Run Ranges of northeastern Nevada, whitebark's principal associate is limber pine (Critchfield and Allenbaugh 1969).

In the timberline zone, conditions for tree development are so severe that any species that can become well established is considered a part of the climax community. In Montana and northern Idaho the whitebark pine stands in the timberline zone (above forest line or where subalpine fir becomes stunted) make up the *Pinus albicaulis-Abies lasiocarpa* habitat types (Daubenmire and Daubenmire 1968; Pfister and others 1977). Whitebark pine is also a climax species in other habitat types, mostly on dry sites, in Montana, central Idaho, and western Wyoming, and in Alberta (Baig 1972; Steele and others 1983; Steele and others 1981; Weaver and Dale 1974). *Pinus albicaulis / Vaccinium scoparium* is probably the most widespread and abundant habitat type that includes pure whitebark pine stands in the Rocky Mountains. Various aspects of the ecology of this habitat type in Montana and Wyoming have been described (Forcella 1978; Forcella and Weaver 1977; Weaver and Dale 1974).

In the subalpine forest of the Northern Rockies whitebark pine is a principal long-lived seral component of the *Abies lasiocarpa / Luzula hitchcockii* and *Abies lasiocarpa-Pinus albicaulis /Vaccinium scoparium* habitat types (Pfister and others 1977). Prior to the early 1900's whitebark pine was apparently more abundant in the subalpine forest as a result of natural fires, which favored its survival and regeneration in comparison with competing fir and spruce (Arno 1986).

Principal undergrowth species in Rocky Mountain and northern Cascade stands include grouse whortleberry (*Vaccinium scoparium*), mountain arnica (*Arnica latifolia*), red mountain heath (*Phyllodoce empetriformis*), rustyleaf menziesia (*Menziesia ferruginea*), smooth woodrush (*Luzula hitchcockii*), beargrass (*Xerophyllum tenax*), elk sedge (*Carex geyeri*), Parry rush (*Juncus parryi*), Ross sedge (*Carex rossii*), and Idaho fescue (*Festuca idahoensis*). In south-central Oregon the primary undergrowth species are long-stolon sedge (*Carex pensylvanica*) and Wheeler bluegrass (*Poa nervosa*) (Hopkins 1979). Undergrowth is sparse in Sierra Nevada stands. Common juniper (*Juniperus communis*) is a major undergrowth plant in Alberta stands (Baig 1972).

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting—Whitebark pine is monoecious. The female strobili and cones develop near the tip of upper crown branches, while the male or pollen strobili develop throughout the crown on the current year's growth. Whitebark pine flowers are receptive, and pollen is shed during the first half of July, but at some midelevation sites the species probably flowers in June. The ripe pollen strobili are a distinct carmine, which distinguishes them from the yellow pollen strobili of limber pine. The importance of various factors limiting pollination and fertilization is unknown. The isolation of some individual trees and small populations planted by birds such as Clark's nutcracker may prevent pollination. Also, animal planting of genetically similar seeds in a given area might increase the level of self-pollination, which is less successful in pines than cross-pollination.

The female or seed cones ripen by early September of the second year (USDA FS 1974). Although there are no good exterior signs of cone and seed ripeness, the cones become somewhat loose and can be pulled apart after September 1.

Seed Production and Dissemination—Large seed crops are produced at irregular intervals, with smaller crops and crop failures in between. Cone crops may be produced more frequently in the southern parts of whitebark pine's distribution (Bailey 1975). In a Sierra Nevada study area, whitebark pine cone crops were moderate to heavy in each of 4 years, 1973 to 1976 (Tomback 1978). A study of 29 whitebark pine stands in the Northern Rockies found that cone production averaged about 6,000 per acre (14,000 per hectare) over an 8-year period (Weaver and Forcella 1986). Seeds number from 2,200 to 3,000/lb (4,850 to 6,600/kg) (USDA FS 1974).

The large, heavy, wingless seeds are borne in a dense, fleshy, egg-shaped cone usually 2 to 3 inches (5 to 8 cm) long. This cone is unusual among North American pines in that it evidently remains closed (indehiscent) after ripening rather than spreading its scales to release seeds (Tomback 1981). If the cone falls to the ground, it disintegrates rapidly by decay and depredations by animals. Observations in southwestern Alberta indicate that groups of whitebark pine seedlings often appear around the rotting residue of cones (Day 1967).

In most stands, however, only a small fraction of the cones are allowed to fall in this manner. Instead, Clark's nutcrackers and red squirrels attack the ripening cones in the tree tops during August, September, and October. As a result of cone predation, it is quite common to find no evidence of cones in a whitebark pine stand except when a careful search is made for cone scales on the ground (Bailey 1975).

Clark's nutcrackers apparently have an essential role in planting whitebark pine and limber pine seeds (Hutchings and Lanner 1982; Lanner 1980; Lanner and Vander Wall 1980; Tomback 1978). Nutcrackers can carry as many as 150 whitebark pine seeds in their sublingual pouch, and they cache groups of one to five seeds in the soil at a depth of 1 inch (2 to 3 cm), suitable for germination. Nutcrackers cached an estimated 13,600 limber pine seeds per acre (33,600/hectare) in one open burned area during one summer. Whitebark pine seeds sustain these birds much of the year, but a large proportion of the seed caches go unrecovered.

Evidence indicates that seed planting by Clark's nutcrackers facilitates the regeneration and spread of whitebark pine. Despite its heavy wingless seed, this species often regenerates promptly on burned or clearcut areas where the seed source is locally absent. Moreover, whitebark pine seedlings in open areas often arise together in tight clumps of two to five. The species has become established atop a young geologic island—Wizard Island in Crater Lake, OR (Jackson and Faller 1973)—where seed dispersal by birds would have been necessary. Lone whitebark pine trees and saplings grow along alpine ridges often a few miles from the nearest possible seed source (Arno and Hammerly 1984). Numerous clumped whitebark pine seedlings and saplings can be found far from a seed source in lower elevation forests (for example, with ponderosa pine), where whitebark pine does not develop beyond sapling stage. Clark's nutcrackers migrate down to these lower elevation stands in autumn bringing whitebark pine seeds with them (Arno and Hammerly 1984; Tomback 1978).

Various mammals also transport and cache whitebark pine seeds. Red squirrels harvest large quantities of whitebark pine cones and store them in rotten logs and in the ground. Black bears and grizzly bears raid many of these cone caches, scattering many seeds. Chipmunks, golden-mantled ground squirrels, and deer mice eat loose seeds and also cache seeds that may ultimately germinate. Red squirrels also cache whitebark pine seeds; from three to 176 seeds per cache have been found (Kendall 1981).

Some seeds probably fall onto favorable seedbeds beneath or near the parent trees. Seeds may occasionally be carried by snow avalanches into lower elevations. Because of periodic disturbances and cold air drainage in avalanche chutes, whitebark pine saplings often occupy sites at relatively low elevations.

The poor germination rate of whitebark pine seed is apparently related to the development and condition of the embryo and to seedcoat factors. Seeds from three Canadian sources germinated poorly, despite a variety of seedcoat scarification techniques with and without cold stratification (Pitel and Wang 1980). The best results were obtained when a small cut was made in the heavy seedcoat and this was placed adjacent to germination paper to facilitate water uptake. The seedcoat is evidently a major cause of delayed regeneration or seed dormancy. Another factor explaining the relatively low germination was the low proportion of seeds with fully developed embryos. In another test, using seed collected from Idaho, 61 percent of the seed germinated after clipping of the seedcoat (Pitel 1981). Stratification for 60 days plus clipping resulted in 91 percent germination. Cold stratification for at least 150 days followed by cracking of the seedcoat has been fairly successful, resulting in 34 percent germination (Hoff 1980).

Seedling Development—Germination is epigeal (USDA FS 1974). The newly germinated seedlings of whitebark pine are large compared to other mountain conifers. Cotyledons number seven to nine (Hitchcock and others 1969), and while still in the cotyledon stage, the seedlings are 3 to 4 inches (8 to 10 cm) tall, with a 5- to 7-inch (13- to 18-cm) taproot (Day 1967). Whitebark pine germinants and seedlings are often common in burned or other disturbed areas. Germinants can also be found in the midst of alpine tundra vegetation.

Vegetative Reproduction—Unlike associated subalpine fir, Engelmann spruce, and mountain hemlock, whitebark pine spreads only to a minor extent through layering—rooting of lower branches that are pressed against moist ground. At the limit of tree growth, whitebark pine forms islands of shrublike growth (flagged krummholz and cushion krummholz, see fig. 5), similar in general appearance to the layered krummholz of fir and spruce described by Marr (1977). A recent inspection of whitebark pine krummholz in the Montana Bitterroot Range confirmed that layering occurs (Arno 1981). Investigation revealed that much of the spread of an individual krummholz plant results from branches extending horizontally from a central point; but also that in some plants these long branches become pressed into the surface soil and have developed large roots, which clearly constitutes layering.

Whitebark pine is easily grafted on stock plants of either whitebark pine or western white pine. The grafts grow much faster when the stock plant is western white pine (Johnson 1981).

Sapling and Pole Stages to Maturity

Growth and Yield—Whitebark pine is a slow-growing, long-lived tree. It can attain small to moderately large size after 250 or more years depending on site conditions. Growth and yield information on this species is scarce, because it has been of little interest for commercial timber production. Occasionally old-growth whitebark pine makes up a modest proportion of the timber harvested in moist, high-elevation stands.

In Montana, the best sites for whitebark pine timber growth are generally in the *Abies lasiocarpa / Luzula hitchcockii* habitat type, *Menziesia ferruginea* phase (Pfister and others 1977). Although whitebark pines of good form and moderately large size (dominant trees 20 to 30 inches [50 to 75 cm] in d.b.h. and 70 to 100 ft [21 to 30 m] tall at 250 to 300 years of age) sometimes develop on these sites, associated Engelmann spruce grows larger and is the primary object of management. In some commercial forest sites between 5,000 and 6,000 ft (1,520 and 1,830 m) in southwestern Alberta, whitebark pine grows larger than associated lodgepole pine and spruce (Day 1967). In south-central Oregon, annual yields of merchantable timber in a lodgepole pine-whitebark pine type were estimated to be about 29 ft^3/acre (2.0 m^3/ha) (Hopkins 1979).

On the best sites where whitebark pine is a component of the spruce-subalpine fir forest, it produces timber of good quality with only a moderate amount of defect. The resulting lumber has properties similar to those of western white pine (Kasper and Szabo 1970) but is graded lower largely because of its slightly darker appearance (Wilson 1981).

At higher elevations where the species is abundant, it forms a short tree with large branches and is unsuitable for timber production. Detailed information on biomass and productivity in some of the pure, high-elevation whitebark pine stands—*Pinus albicaulis /Vaccinium scoparium* habitat type—suggests that annual yields of merchantable timber are very low, about 10 to 20 ft^3/acre (0.7 to 1.4 m^3/ha) (Forcella and Weaver 1977; Pfister and others 1977; Weaver and Dale 1974).

On favorable sites near the forest line this species develops into a large, single-trunk tree commonly 35 to 65 ft (11 to 20 m) tall (fig. 2) and has a life span of 500 years or

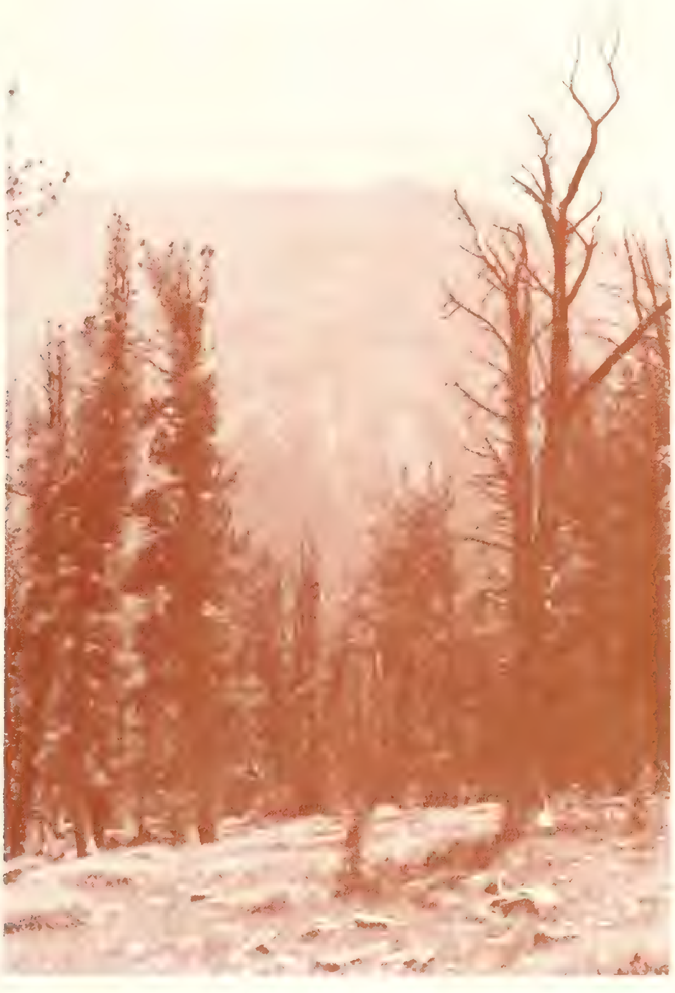

Figure 2—Pure stand of mature whitebark pine on a south-facing slope at 8,400 ft (2,560 m) elevation in western Montana.

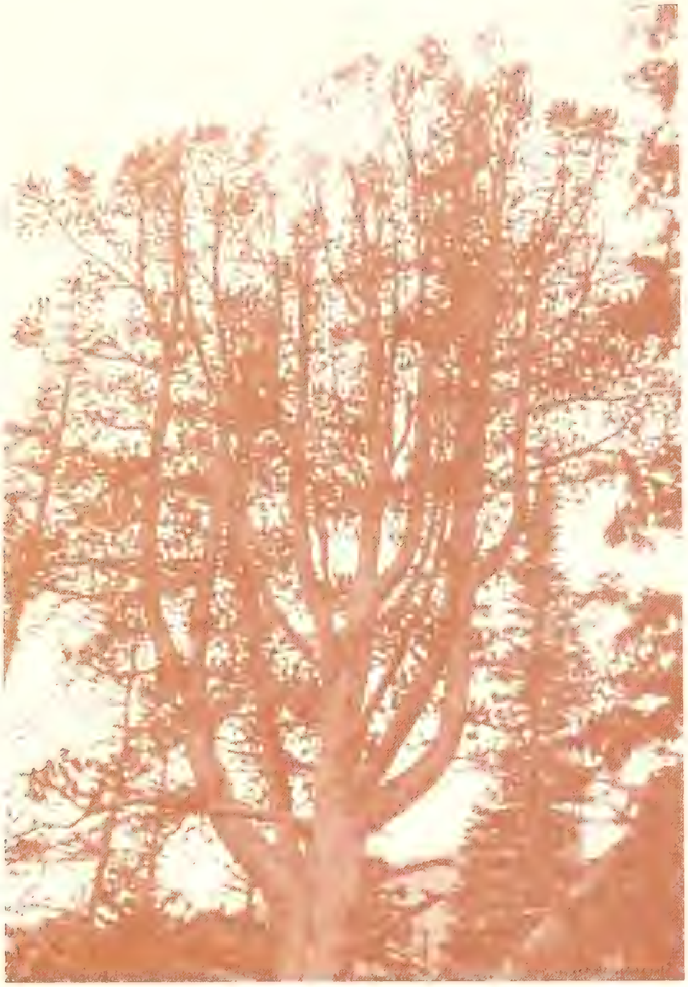

Figure 3—Upswept branch-trunks of an ancient whitebark pine in the timberline zone.

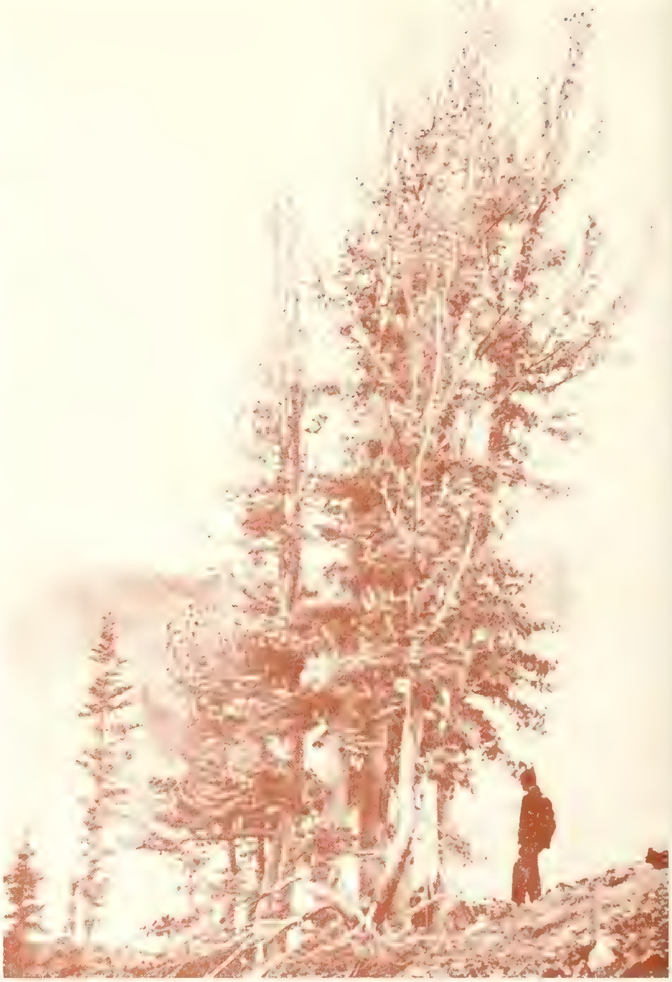

Figure 4—Multistemmed growth form of whitebark pine at tree line in the northeastern part of the Olympic Mountains, WA.

more. The oldest individuals in some cold, dry sites probably attain 1,000 years. The ancient trees often have a broad crown composed of large ascending branch-trunks (fig. 3). The largest recorded whitebark pine, growing in central Idaho's Sawtooth Range, is 105 inches (267 cm) in d.b.h. and 69 ft (21 m) tall (AFA 1986). Upwards through the timberline zone, whitebark pine becomes progressively shorter and assumes multistemmed growth forms (fig. 4) evidently arising from the germination of nutcracker seed caches (Furnier and others 1987; Linhart and Tomback 1985).

At its upper limits, whitebark pine is reduced to shrublike growth forms (fig. 5) (Clausen 1965). Such krummholz stands are often extensive on wind-exposed slopes and ridgetops. Primary causes of krummholz are thought to be inadequate growing season warmth, which prevents adequate growth, maturation, and hardening (cuticle development) of new shoots (Tranquillini 1979). As a result, shoots are easily killed by frost or by heating and desiccation on sunny days in early spring when the soil and woody stems are frozen and thus little water is available to replace transpiration losses. Mechanical damage from ice particles in the wind is also a factor limiting krummholz growth to microsites where snowpack accumulates and provides protection from sun and wind.

Rooting Habit—On most sites whitebark pine develops a deep and spreading root system. It is well-anchored into the rocky substrate and is seldom uprooted despite its large, exposed crown and the violent winds to which it is subjected. Wind-thrown whitebark pines growing on moraines in Wyoming show pancake-like root systems only 16 inches (40 cm) deep (Lanner 1981). Such shallow rooting probably occurs also where the species inhabits high-elevation bogs.

Reaction to Competition—Although whitebark pine has been tentatively rated very intolerant of competition or shade (Baker 1949), recent observers (Day 1967; Pfister and others 1977; Steele and others 1983) believe that it is intermediate or intolerant, about equivalent to western white pine or interior Douglas-fir. Whitebark pine is less tolerant than subalpine fir, spruce, and mountain hemlock; however, it is more tolerant than lodgepole pine and subalpine larch. Whitebark pine should, therefore, be classed as intermediate in tolerance to shade.

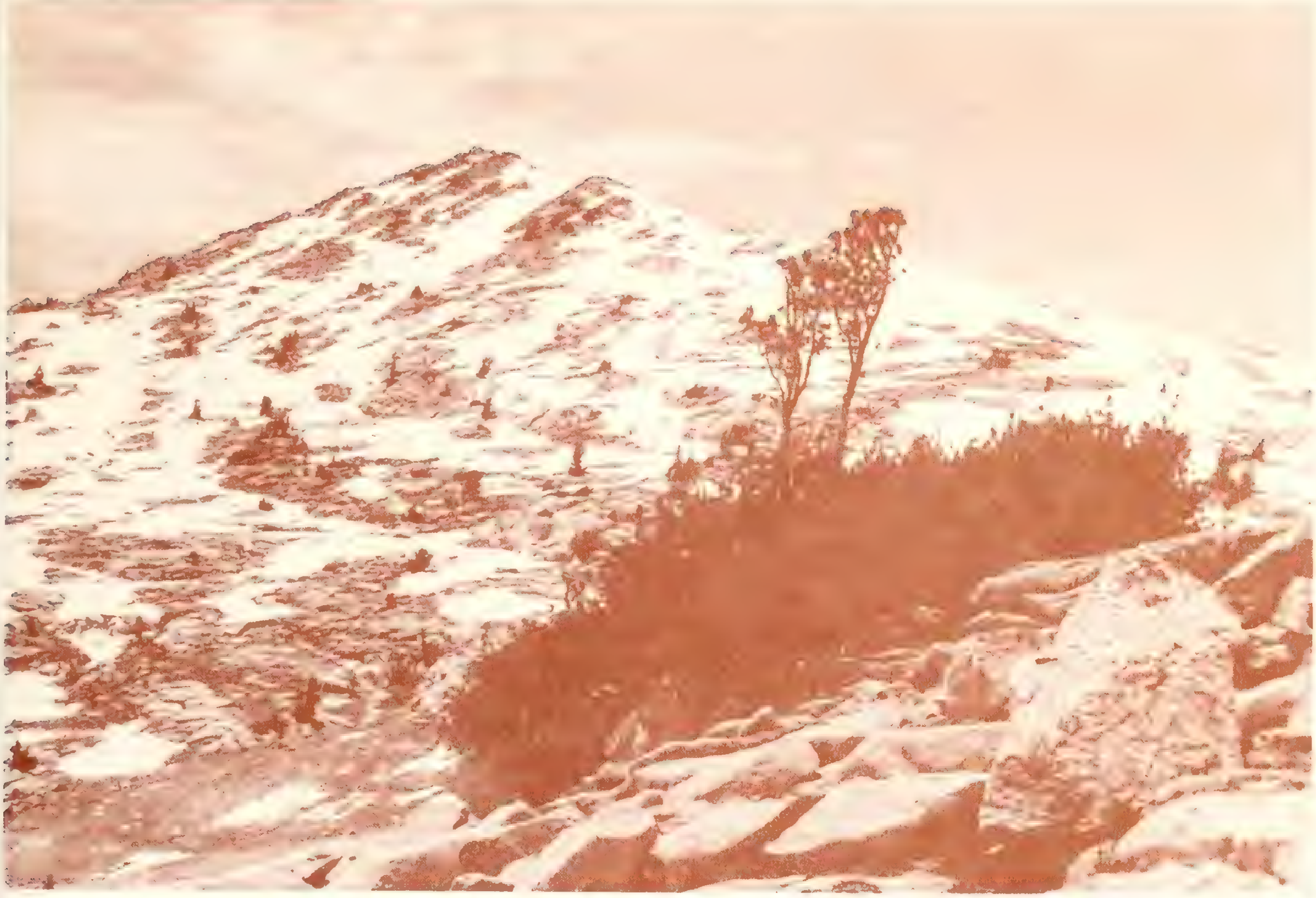

Figure 5—Krummholz whitebark pine at 10,600-ft (3,230-m) Granite Pass, Sequoia-Kings Canyon National Park in the California Sierra Nevada. The krummholz "cushion" is protected by winter snowpack; the wind-battered upper branches are called "flags."

Whitebark pine cannot become a climax forest dominant in moist, wind-sheltered sites where its tolerant associates are capable of forming a closed stand. But it can become a long-lived seral dominant on these sites as a result of stand replacement by fire, snow avalanche, and other major disturbances.

On a broad range of dry, wind-exposed sites, whitebark pine is a climax or near-climax species that persists indefinitely in association with subalpine fir and other tolerant species because it is hardier, more drought tolerant, more durable, and longer lived. Even on these severe sites, however, a successional trend may be observable on a small scale; whitebark pine pioneers on an open site and is later surrounded and locally replaced by tolerant fir and hemlock (Franklin and Dyrness 1973). In dry areas of Wyoming's Wind River and in south-central Oregon, whitebark pine forms a coclimax with lodgepole pine in dense subalpine forest stands (Hopkins 1979; Steele and others 1983).

Whitebark pine often regenerates following wildfire and after clearcutting (with or without site preparation) on southern exposures or ridgetops. Observations of whitebark pine regeneration in natural stands suggest that this species could be perpetuated on relatively dry sites under a variety of even-aged or uneven-aged silvicultural systems. To establish whitebark pine regeneration on moist sites, appreciable stand opening and light, localized site preparation would probably be necessary. Watershed values (and often esthetic values) are very high on these sites, however, and use of heavy equipment could be very damaging. Wind throw and wind breakage is a danger to residual trees, especially spruce and fir, in partial cuttings. Whitebark pine can be regenerated by outplanting seedlings or seeds in mineral soil or at the soil-litter interface (McCaughey 1988). Such artificial regeneration might allow the establishment of whitebark pine on sites where it has been scarce because of lack of seed caching by the Clark's nutcracker.

Damaging Agents—Mountain pine beetle (*Dendroctonus ponderosae*) is by far the most damaging insect in mature stands of whitebark pine. A large proportion of the mature whitebark pine in the Northern Rockies was killed by this insect between 1909 and 1940 (Arno 1970; Ciesla and Furniss 1975; Furniss and Carolin 1977). Epidemics evidently spread upward into the whitebark pine forest after becoming established in the lodgepole pine forests below. In the 1970's, an epidemic developing in lodgepole pine in the Flathead National Forest of Montana killed most of the whitebark pine in some areas. This insect usually kills only the larger whitebark pine trees because such trees have an inner bark layer thick enough for the larvae to inhabit. Small trees are also killed in areas of intense infestation.

Less damaging insect infestations are caused by aphids (*Essigella gillettei*) that feed on needles, mealybugs (*Puto cupressi* and *P. pricei*) that feed on trunks and branches, and the lodgepole needletier (*Argyrotaenia tabulana*), a potentially destructive defoliator. At least one species of ips, the Monterey pine ips (*Ips mexicanus*), infests the bole, and *Pityogenes carinulatus* and *P. fossifrons* also infest the bole (Furniss and Carolin 1977). Two species of *Pityophthorus* (*P. aquilonius* and *P. collinus*) have been collected from whitebark pine (Bright 1968). The ponderosa pine cone beetle (*Conophthorus ponderosae*) infests cones of whitebark pine (Wood 1981).

The principal disease is the introduced white pine blister rust (caused by *Cronartium ribicola*). Blister rust is particularly destructive where the ranges of whitebark pine and blister rust coincide with good conditions for infection. This occurs where adequate moisture permits infection of local *Ribes* spp. (currant and gooseberry bushes, which are the rust's alternate host) in early summer and prevents drying of the infected *Ribes* leaves throughout the summer. Where there is a source of inoculum from lowland forests, the spores that infect pine can be carried by wind to the trees, but cool, moist conditions are needed for infection of the pine host (Bedwell and Childs 1943). Blister rust damage is severe and prevents tree development in some timberline areas of the northern Cascades, northern Idaho, and northwestern Montana where whitebark pine is the major pioneer species. Resistance of whitebark pine is discussed under "genetics" in this paper.

Several other diseases infect whitebark pine, generally with minor consequences (Hepting 1971; Hiratsuka and Funk 1976; Smith 1956). These diseases are stem infections that produce cankers (some very similar to blister rust), such as *Atropellis pinicola, A. piniphila, Dasyscypha pini,* and *Gremmeniella abietina*; a wood rot organism, *Phellinus pini*; several root and butt rots caused by *Heterobasidion annosum, Phaeolus schweinitzii,* and *Poria subacida*; and several needle cast fungi including *Lophodermium nitens, L. pinastri, Bifusella saccata,* and *B. linearis.* When foliage is covered by snow for long periods, a snow mold, *Neopeckia coulteri*, appears (Hepting 1971; Hiratsuka and Funk 1976; Smith 1956).

The dwarf mistletoes (*Arceuthobium* spp.) cause severe local mortality in whitebark pine. The most widespread species is the limber pine dwarf mistletoe (*A. cyanocarpum*). In the Northern Rockies, the lodgepole pine dwarf mistletoe (*A. americanum*) occasionally occurs on whitebark pine where this tree grows in infested lodgepole pine stands. In the Oregon Cascades the hemlock dwarf mistletoe (*A. tsugense*) is damaging to whitebark pine (Hawksworth and Wiens 1972).

In addition to these parasitic organisms, several harmless saprophytes grow on whitebark pine: *Dasyscypha agassizii* on dead bark and cankers of blister rust, *D. arida, Tympanis pinastri,* and *Phoma harknessii* on twigs (Hepting 1971). *Cenococcum graniforme* has been identified as an ectotrophic mycorrhizal fungus of whitebark pine (Trappe 1962).

Wildfire is an important vegetation recycling force in whitebark pine stands, although long intervals (mean intervals from 50 to 300 years or more depending on the site) usually occur between fires in a given grove (Arno 1980). Lightning has been the major cause of fires in most stands; however, increased recreational use of forests results in accidental fires. Many of the fires have spread upslope into whitebark pine after developing in lower forest zones. Tiny spot fires are most common because fuels are generally sparse and conditions moist and cool. Nevertheless, occasional warm and dry periods accompanied by strong winds allow fires to spread. Spreading fires often remain on the surface and kill few large trees, but under extreme conditions, severe wind-driven fires burn sizable stands (Arno 1980). Wildfire (enhanced by fuels created by epidemics of *Dendroctonus ponderosae* in lodgepole and whitebark pine), followed by seed dissemination by Clark's nutcrackers, may be the principal means by which whitebark pine becomes established in the more productive sites near its lower elevational limits. Conversely, after a severe fire on dry, wind-exposed sites, regeneration of whitebark pine (often the pioneer species) may require several decades.

Wind breakage of the crowns or boles occurs when unusually heavy loads of wet snow or ice have accumulated on the foliage. This damage is prevalent in large old trees having extensive heart rot. Snow avalanches also are an important damaging agent in some whitebark pine stands.

SPECIAL USES

Whitebark pine's greatest values are for wildlife habitat, watershed protection, and esthetics. Potential use for timber on a sustained yield basis is very limited in most areas.

Whitebark pine seeds are a principal year-round food for the Clark's nutcracker and red squirrels. Seeds are an important, highly nutritious food source for many other seed-eating birds and small mammals, as well as for black bears and grizzly bears (Kendall 1981; Mealey 1980).

Blue grouse feed and roost in whitebark pine crowns during much of the year. This tree provides both hiding and thermal cover in sites where few if any other trees grow. The large hollow trunks of old trees and snags provide homesites for cavity-nesting birds. The seeds of whitebark pine have occasionally been used as a secondary food source by Native Americans (Malouf 1969).

Whitebark pine helps to stabilize snow, soil, and rocks on steep terrain and has potential for use in land reclamation projects at high elevation (Pitel and Wang 1980). It also provides shelter and fuel for hikers and campers and is a very picturesque mountain tree.

GENETICS

Most of the wide phenotypic variation in whitebark pine is apparently the result of differences in site and climate. Nevertheless, at least two distinct forms are recognized—the alpine and subalpine forms, one a prostrate shrub and the other a fairly typical upright tree (Clausen 1965).

Determination of whether or not these are genetic races will have to await genetic tests. Enzyme studies suggested that high-elevation forms of Engelmann spruce and subalpine fir do have a genetic basis (Grant and Mitton 1977), but another study showed that a prostrate form of the European stone pine (*Pinus cembra*), closely related to whitebark, can spontaneously produce an erect tree stem (Holzer 1975).

Resistance to white pine blister rust is the most notable phenotypic variation observed in whitebark pine. The species is extremely susceptible to blister rust both in the field and nursery in artificial inoculation tests and has been rated by many people as the most susceptible of all the world's white pines (Bingham 1972). In stands where mortality has been as high as 80 to 90 percent, however, many individuals have survived and some are free of rust symptoms. Testing, using artificial inoculation methods to expose seedlings from uninfected wild parents, has demonstrated resistance to be genetic (Hoff and others 1980). Four main defense mechanisms were observed: absence of infections of needles or stem; shedding of infected needles before the fungus could reach the stem; a chemical interaction between the fungus and short-shoot tissue that killed the fungus; and chemical reactions in the stem that killed host cells, with subsequent walling off of the fungus.

A small trial plantation of first-generation wind-pollinated seedlings from resistant whitebark pine parents was established at Marks Butte near Clarkia, ID, in 1979 (Hoff 1980). Results of this trial may ultimately help reestablish the species in areas where mortality is high and where the impact of birds and rodents on the remaining seed supply is therefore greater.

Many attempts have been made to cross whitebark pine with the other four white pine species in its subsection *Cembrae* and with most species in subsection *Strobi*. Almost all have ended in failure or inconclusive results (Bingham and others 1972). Only the cross with limber pine, from subsection *Strobi*, offers slight hope (Critchfield 1981). No putative hybrids of whitebark pine have been identified in natural stands.

REFERENCES

American Forestry Association. 1986. National register of big trees. American Forests. 92(4): 21-52.

Arno, S. F. 1970. Ecology of alpine larch (*Larix lyallii* Parl.) in the Pacific Northwest. Missoula, MT: University of Montana. 264 p. Dissertation.

Arno, S. F. 1980. Forest fire history in the Northern Rockies. Journal of Forestry. 78(8): 460-465.

Arno, S. F. 1981. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT.

Arno, S. F. 1986. Whitebark pine cone crops—a diminishing source of wildlife food? Western Journal of Applied Forestry. 1(3): 92-94.

Arno, S. F.; Hammerly, R. 1984. Timberline—mountain and arctic forest frontiers. Seattle, WA: The Mountaineers. 304 p.

Baig, M. N. 1972. Ecology of timberline vegetation in the Rocky Mountains of Alberta. Calgary, AB: University of Calgary. Dissertation.

Bailey, D. K. 1975. *Pinus albicaulis*. Curtis's Botanical Magazine. 180(3): 140-147.

Baker, F. S. 1944. Mountain climates of the western United States. Ecological Monographs. 14(2): 233-254.

Baker, F. S. 1949. A revised tolerance table. Journal of Forestry. 47(3): 179-182.

Bedwell, J. L.; Childs, T. W. 1943. Susceptibility of whitebark pine to blister rust in the Pacific Northwest. Journal of Forestry. 41: 904-912.

Bingham, R. T. 1972. Taxonomy, crossability, and relative blister rust resistance of 5-needled white pines. In: Biology of rust resisitance in forest trees: proceedings of a NATO-IUFRO advanced study institute; 1969 August 17-24; Moscow, ID. Misc. Publ. 1221. Washington, DC: U.S. Department of Agriculture: 271-280.

Bingham, R. T.; Hoff, R. J.; Steinhoff, R. J. 1972. Genetics of western white pine. Res. Pap. WO-12. Washington, DC: U.S. Department of Agriculture, Forest Service. 18 p.

Bright, Donald E., Jr. 1968. Three new species of *Pityophthorus* from Canada (Coleoptera: Scolytidae). Canadian Entomologist. 100: 604-608.

Ciesla, W. M.; Furniss, M. M. 1975. Idaho's haunted forests. American Forests. 81(8): 32-35.

Clausen, J. 1965. Population studies of alpine and subalpine races of conifers and willows in the California High Sierra Nevada. Evolution. 19(1): 56-68.

Critchfield, W. B. 1981. [Personal communication]. Berkeley, CA: U.S. Department of Agriculture, Forest Service.

Critchfield, W. B.; Allenbaugh, G. A. 1969. The distribution of Pinaceae in and near northern Nevada. Madroño. 20: 12-26.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agriculture Experiment Station. 104 p.

Day, R. J. 1967. Whitebark pine in the Rocky Mountains of Alberta. Forestry Chronicle. 43(3): 278-282.

Forcella, F. 1978. Flora and chorology of the *Pinus albicaulis-Vaccinium scoparium* association. Madroño. 25: 139-150.

Forcella, F.; Weaver, T. 1977. Biomass and productivity of the subalpine *Pinus albicaulis-Vaccinium scoparium* association in Montana, USA. Vegetatio. 35(2): 95-105.

Franklin, J. F. 1966. [Personal communication]. Corvallis, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory.

Franklin, J. F.; Dyrness, C. T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portand, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Furnier, Glenn R.; Knowles, Peggy; Clyde, Merlise A.; Dancik, Bruce P. 1987. Effects of avian seed dispersal on the genetic structure of whitebark pine populations. Evolution. 41(3): 607-612.

Furniss, R. L.; Carolin, V. M. 1977. Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture, Forest Service. 654 p.

Grant, M. C.; Mitton, J. B. 1977. Genetic differentiation among growth forms of Engelmann spruce and subalpine fir at tree line. Arctic and Alpine Research. 9(3): 259-263.

Hawksworth, F. G.; Wiens, D. 1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). Agric. Handb. 401. Washington, DC: U.S. Department of Agriculture, Forest Service. 234 p.

Hepting, George H. 1971. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture, Forest Service. 658 p.

Hiratsuka, Y.; Funk, A. 1976. Additional records of *Gremmeniella abietina* in western Canada. Plant Disease Reporter. 60: 631.

Hitchcock, C. L.; Cronquist, A.; Ownbey, M.; Thompson, J. W. 1969. Vascular plants of the Pacific Northwest: Part 1. Seattle: University of Washington Press. 914 p.

Hoff, R. J. 1980. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Moscow, ID.

Hoff, R. J.; Bingham, R. T.; McDonald, G. I. 1980. Relative blister rust resistance of white pines. European Journal of Forest Pathology. 10: 307-316.

Holzer, Kurt. 1975. Genetics of *Pinus cembra.* Annales Forestales. 6/5: 139-158.

Hopkins, W. E. 1979. Plant associations of the Fremont National Forest. Publ. Ecol. 79-004. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 106 p.

Hutchings, H. E.; Lanner, R. M. 1982. The central role of Clark's nutcracker in the dispersal and establishment of whitebark pine. Oecologia. 55: 192-201.

Jackson, M. T.; Faller, A. 1973. Structural analysis and dynamics of the plant communities of Wizard Island, Crater Lake National Park. Ecological Monographs. 43: 441-461.

Johnson, LeRoy. 1981. [Personal communication]. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Kasper, J. B.; Szabo, T. 1970. The physical and mechanical properties of whitebark pine. Forestry Chronicle. 46: 315-316.

Kendall, K. C. 1981. Bear use of pine nuts. Bozeman, MT: Montana State University. 25 p. Thesis.

Lanner, R. M. 1980. Avian seed dispersal as a factor in ecology and evolution of limber and whitebark pines. In: Proceedings, sixth North American forest biology workshop. Edmonton, AB: University of Alberta. 48 p.

Lanner, R. M.; Vander Wall, S. B. 1980. Dispersal of limber pine seed by Clark's nutcracker. Journal of Forestry. 78(10): 637-639.

Lanner, R. M. 1981. [Personal communication]. Logan, UT: Utah State University.

Linhart, Y. B.; Tomback, D. F. 1985. Seed dispersal by nutcrackers causes multi-trunk growth form in pines. Oecologia. 67: 107-110.

Malouf, Carling. 1969. The coniferous forests and their uses in the northern Rocky Mountains through 9,000 years of prehistory. In: Proceedings, 1968 symposium, coniferous forests of the Northern Rocky Mountains. Missoula, MT: University of Montana, Center for Natural Resources: 271-280.

Marr, J. W. 1977. The development and movement of tree islands near the upper limit of tree growth in the southern Rocky Mountains. Ecology. 58(5): 1159-1164.

McAvoy, B. 1931. Ecology survey of the Bella Coola region. Botanical Gazette. 92: 141-171.

McCaughey, W. W. 1988. Determining what factors limit whitebark pine germination and seedling survival in high elevation subalpine forests. Unpublished paper, Study No. INT-4151-020, on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Bozeman, MT.

Mealey, S. P. 1980. The natural food habits of grizzly bears in Yellowstone National Park, 1973-1974. In: Markinka, C. J.; McArthur, K. L., eds. Bears—their biology and management: Proceedings, fourth international conference on bear research and management. Conf. Ser. 3. Kalispell, MT: Bear Biology Association: 281-292.

Mehringer, P. J., Jr.; Arno, S.; Petersen, K. 1977. Postglacial history of Lost Trail Pass Bog, Bitterroot Mountains, Montana. Arctic and Alpine Research. 9(4): 345-368.

Nimlos, T. J. 1963. Zonal great soil groups in western Montana. Proceedings, Montana Academy of Sciences. 23: 3-13.

Pfister, R. D.; Kovalchik, B. L.; Arno, S.; Presby, R. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Pitel, J. A. 1981. [Personal communication]. Chalk River, ON: Canadian Forestry Service, Petawawa National Forestry Institute.

Pitel, J. A.; Wang, B. S. P. 1980. A preliminary study of dormancy in *Pinus albicaulis* seeds. Canadian Forestry Service, Biomonthly Research Notes. Jan.-Feb.: 4-5.

Smith, Richard S., Jr. 1956. Needle casts of high-altitude white pines in California. Plant Disease Reporter. 56: 102-103.

Society of American Foresters. 1980. Forest cover types of the United States and Canada. Eyre, F. H. ed. Washington, DC: Society of American Foresters. 148 p.

Steele, Robert; Cooper, Stephen V.; Ondov, David M.; [and others]. 1983. Forest habitat types of eastern Idaho - western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; [and others]. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Thompson, L. S.; Kuijt, J. 1976. Montane and subalpine plants of the Sweetgrass Hills, Montana, and their relationship to early post-glacial environments of the Northern Great Plains. Canadian Field Naturalist. 90(4): 432-448.

Tomback, D. F. 1978. Foraging strategies of Clark's nutcracker. Living Bird. 16(1977): 123-160.

Tomback, D. F. 1981. Notes on cones and vertebrate-mediated seed dispersal of *Pinus albicaulis* (Pinaceae). Madroño. 28(2): 91-94.

Tranquillini, W. 1979. Physiological ecology of the alpine timberline. New York: Springer-Verlag. 137 p.

Trappe, J. M. 1962. Fungus associates of ectotrophic mycorrhizae. Botanical Review. 28: 538-606.

U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service. 883 p.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy. Agric. Handb. 436. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 754 p.

Weaver, T.; Dale, D. 1974. *Pinus albicaulis* in central Montana: environment, vegetation and production. American Midland Naturalist. 92: 222-230.

Weaver, T.; Forcella, F. 1986. Cone production in *Pinus albicaulis* forests. In: Shearer, R. C., compiler. Proceedings—conifer tree seed in the Inland Mountain West symposium; 1985 August 5-6; Missoula, MT. Gen. Tech. Rep. INT-203. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 68-76.

Wilson, George R. 1981. [Personal communication]. Columbia Falls, MT: U.S. Department of Agriculture, Forest Service.

Wood, S. L. 1981. [Personal communication]. Provo, UT: Brigham Young University. [Supplied by M. Furniss.]

Arno, Stephen F.; Hoff, Raymond J. 1989. Silvics of whitebark pine (*Pinus albicaulis*). Gen. Tech. Rep. INT-253. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Whitebark pine (*Pinus albicaulis*) is a long-lived tree inhabiting the upper subalpine forest and timberline zone on high mountains of Western North America. The species' habitat, life history, growth and yield, mortality factors, special uses, and genetics are described.

KEYWORDS: forest ecology, subalpine forests, grizzly bear habitat, krummholz, animal seed dispersal

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Microcomputer Software System for Generating Population Statistics From Electrofishing Data—User's Guide for MicroFish 3.0

John S. Van Deventer
William S. Platts

THE AUTHORS

JOHN S. VAN DEVENTER is a computer scientist for the Riparian-Stream Ecology and Management Project of the Intermountain Research Station located at the Forestry Sciences Laboratory in Boise, ID. He received a B.S. degree in fisheries biology and M.S. degrees in natural resource management (specializing in statistics and information systems) from Humboldt State University. He is completing a Ph.D. degree in wildlife at the University of Idaho, with an emphasis in computer science and applied statistics. Previously he worked in data processing as a senior systems analyst for the Boise Cascade Corporation and for the Corporate Information Systems Division of the Morrison-Knudsen Company, Inc.

WILLIAM S. PLATTS (retired) was a research fishery biologist for the Intermountain Research Station located at the Forestry Sciences Laboratory in Boise, ID. He received a B.S. degree in conservation education from Idaho State University and M.S. and Ph.D. degrees in fisheries from Utah State University. He previously worked as a regional fishery biologist and supervisor in law enforcement with the Idaho Fish and Game Department, as an Idaho zone fishery biologist for the U.S. Forest Service, and as a consultant to the Surface Environment and Mining (SEAM) program. He has been in his present position since 1976.

COPYING INFORMATION

MicroFish 3.0 is available from the American Fisheries Society Computer Users Section. The cost is \$6 if you send a disk, \$10 if you don't send a disk. Disks sent must be 5$^1/_4$-inch and double-sided, double-density. Disks should be labeled with the sender's name and address and should be protected with cardboard or a disk mailer to prevent shipping damage. Contact:

Anthony Frank, Librarian
USFWS Great Lakes Fishery Lab
1451 Green Road
Ann Arbor, MI 48105
(313) 994-3331

Once you obtain **MicroFish**, you may distribute the software to other users only under the following conditions:

1. The American Fisheries Society Computer Users Section (or the authors) must be provided the names and addresses of new users so update notices can be distributed.
2. The software must not be modified in any way.
3. A copy of this user's guide must accompany the software.
4. **MicroFish** must be distributed free of charge.

For questions concerning this application, you may contact the author at the following address:

Forestry Sciences Laboratory
Intermountain Research Station
USDA Forest Service
316 E. Myrtle Street
Boise, ID 83702
(208) 334-1457

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

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Microcomputer Software System for Generating Population Statistics From Electrofishing Data— User's Guide for MicroFish 3.0

John S. Van Deventer
William S. Platts

INTRODUCTION

MicroFish is a computer software system that processes electrofishing data obtained by the removal method. **MicroFish** consists of programs written in the BASIC language (compiled using MicroSoft QuickBASIC 3.0) and is functional on all IBM personal computers and compatibles using DOS 2.0 or higher. **MicroFish** was introduced as the Fisheries Population and Statistical Package (FPSP) (Van Deventer and Platts 1985). The software includes:

MicroFish Interactive Program—This program (MF.EXE) calculates maximum-likelihood population estimates based on user input of fish capture data.

MicroFish Statistical Package (Output: Table Format)—This package of subprograms (MFISH.EXE) calculates maximum-likelihood estimates and a series of fisheries statistics including capture probabilities, lengths, weights, and biomass.

MicroFish Statistical Package (Output: Database Format)—Performs the same calculations as the preceding package, except that output is in database format instead of table form.

MicroFish Sample Size Program (2-Dimensions)—The two-dimensional graph displayed by this program (MF-SS2D.EXE) indicates the number of electrofishing passes needed to achieve a desired level of precision. Computer graphics capabilities are required.

MicroFish Sample Size Program (3-Dimensions)—The three-dimensional graph displayed by this program (MF-SS3D.EXE) provides a conceptual foundation for the interrelationships among population size, catchability, electrofishing passes, and precision. Computer graphics capabilities are required.

Examples of output for programs MF.EXE, MFISH.EXE, MFISH-DB.EXE, MF-SS2D.EXE, and MF-SS3D.EXE are shown in appendixes 1, 2, 3, 5, and 6.

MicroFish System Files—The following files are included on the **MicroFish** diskette:

MF	.EXE—the **MicroFish Interactive Program.**
MFISH	.EXE—the **MicroFish Statistical Package (Output: Table Format).**
MFISH-DB	.EXE—the **MicroFish Statistical Package (Output: Database Format).**
MF-SYS	.EXE—a file required by **MicroFish** (of no concern to the user).
MF-SYSDB	.EXE—a file required by **MicroFish** (of no concern to the user).
MF-SS2D	.EXE—the **MicroFish Sample Size Program (2-Dimensions).**
MF-SS3D	.EXE—the **MicroFish Sample Size Program (3-Dimensions).**
MF-SS2D	.FIL—calculation information (input parameters) for MF-SS2D.EXE.
MF-SS3D	.FIL—calculation information (input parameters) for MF-SS3D.EXE.

MF-TEST .DAT—a sample file of fish capture data.
MF-FISH .DAT—a list of fish names and associated numeric codes.
MF-PARM .DAT—a file of parameters that enhance program operation.

BRUN30 .EXE—the compiler runtime module (of no concern to the user).

INSTALLING MICROFISH

This section describes how to load **MicroFish** into your computer. If you haven't already done so, please make a backup copy of **MicroFish**. To make a backup, put the **MicroFish** diskette in your a: diskette drive and a blank, formatted diskette in the b: drive, then type:

copy a:.* b:* OR *diskcopy a: b:.*

Now you are ready to install **MicroFish**.

Installation: Two Disk Drive System

Place the **MicroFish** diskette in one drive and your data diskette in the other. That's all there is to it.

Installation: Hard Disk System

Create a directory for **MicroFish** and copy the **MicroFish** files to it. (The following instructions assume your hard drive is labeled C:.)

1. Type: *C:* (make the C: hard disk drive the current drive.)
2. Type: *cd* (make the root directory the current directory).
3. Type: *md\mf* (make a directory called MF for **MicroFish**)
4. Type: *cd\mf* (change the current directory to the MF directory).
5. Put the **MicroFish** diskette into the A: diskette drive.
6. Type: *copy a:*.** (copy **MicroFish** files to the C:\MF directory.)

Installation is now complete.

HOW TO RUN MICROFISH PROGRAMS

EXAMPLE: MicroFish Interactive Program

1. Type: *MF <enter>*
2. Strike any key to continue
3. Type: *Salmon River <enter>*
4. Type: *Rainbow Trout <enter>*
5. Type: *4 <enter>*
6. Type: *124 <enter> 61 <enter> 35 <enter> 14 <enter>*
7. Type: *0*

Results should be identical to output shown in appendix 1.

EXAMPLE: MicroFish Statistical Package (Output: Tables)

1. Type: *MFISH <enter>* (the title page should show after this)
2. At each pause, strike a key (do this 4 times, 1 for each display screen)
3. Type: *MF-TEST.DAT <enter>* (this is a test data file)
4. Type: *1* (send output to the screen)
5. Type: *0* (to exit)

Results should be identical to output shown in appendix 2.

EXAMPLE: MicroFish Statistical Package (Output: Database Format)

1. Type: *MFISH-DB <enter>* (the title page should show after this)
2. At each pause, strike a key (do this 4 times, 1 for each display screen)
3. Type: *1* (run one data set)

4. Type: *MF-TEST.DAT <enter>* (this is a test data file)
5. Type: *1* (send output to current directory)

A results file, MF-TEST.RES, will be created which should be identical to information shown in appendix 3.

EXAMPLE: MicroFish Sample Size Program (2-D)

1. Type: *MF-SS2D <enter>* (calculations will take some time to complete)
2. Strike any key (to continue after graph is displayed)
3. Type: *n* (to exit)

Results should be identical to output shown in appendix 5.

EXAMPLE: MicroFish Sample Size Program (3-D)

1. Type: *MF-SS3D <enter>* (calculations will take some time to complete)
2. Strike any key (to display graph)
3. Strike any key (to continue after graph is displayed)
4. Type: *n* (to exit)

Results should be identical to output shown in appendix 6.

Data Entry

MICROFISH INTERACTIVE PROGRAM

The **MicroFish Interactive Program** (program MF.EXE) receives data from user input. There are no external files accessed by this program.

Tips for Efficient Program Operation

1. Entering stream and species names are optional. Press *<enter>* to bypass these.

2. After program execution, 2 yes or no (*y* or *n*) questions ask the user if the results are to be printed and if the program is to be exited. Printing and exiting occur only if a *Y* (or a *y*) are entered. So, pressing any key (or *<enter>*) gives a "no" response to these questions.

Program Input

MICROFISH STATISTICAL PACKAGE

The **MicroFish Statistical Package** (programs MFISH.EXE and MFISH-DB.EXE) requires three sets of data input: (1) a fish file called MF-FISH.DAT containing numeric codes and fish names; (2) a parameter file called MF-PARM.DAT that can be used to enhance program operation, including detection of data errors; and (3) one or more fish capture data files. In the latter case the data files are named by the user. MFISH.EXE allows only one fish capture data file; MFISH-DB.EXE can process multiple files simultaneously.

Data files may be created with whichever line editor, text editor, word processor, etc., you have at your disposal. The data files must be saved as DOS text files (ASCII files). Some packages (for example, spreadsheets and word processors) save files under their own format, not as DOS files. In such cases be sure to use the EXPORT or TEXT IN/OUT capabilities to save files in a DOS format. The three required data files are described in detail below.

FISH FILE (MF-FISH.DAT)

This file should be created by the user to contain numeric codes that identify fish species. Each numeric code is followed by a comma and then by the actual fish name. MF-FISH.DAT currently looks like this:

```
1, Salmon: Chinook
2, Trout: Rainbow
3, Trout: Brook
4, Trout: Bull
```

```
  5, Trout: Cutthroat
  6, Trout: Brown
 10, Sucker
 11, Sculpin
100, Whitefish
101, Dace
```

The fish species code must be a whole number from 1 to 1000, inclusive. *The maximum length of the text description of the species code is 16 characters* (excess characters are truncated). If the species code in the fish capture data file fails to contain a corresponding species code in MF-FISH.DAT, an error message will be displayed during execution of the **MicroFish Statistical Package.**

This file need not be modified if the species listed above are those that are encountered by the user. Modify this file as needed to accommodate your specific needs. The user is strongly encouraged to maintain consistency among fish capture data files with regard to the numeric codes used for identifying fish species.

Because the database output option exists (with MFISH-DB.EXE), the naming of fish becomes more important. When combining multiple database files into one large file, it is often useful to sort by fish names in order to group individual species information. If species names are preceded by group names (for example, trout) then fish groups can be sorted together as well.

PARAMETER FILE (MF-PARM.DAT)

Under normal circumstances, this file should remain as is, without user modification. The file contains some user-adjustable parameters that may aid program operation or data error detection. File MF-PARM.DAT looks like this:

```
179
Y
N
scrn:
5
1.5
5000
```

Parameter 1 is the ASCII character for the vertical bar that appears on MFISH.EXE output. A table of ASCII codes exists in the appendix of your BASIC manual. Some printers are not capable of printing ASCII character 179. In such cases change the *179* in line 1 to *73,* which refers to an "I".

Parameter 2 is a parameter that controls error checking and validation of fish capture data. If you are 100 percent certain that your data have been entered in the correct format, you may change this parameter to *N* for somewhat faster program operation.

Parameter 3 controls the ability of MFISH.EXE to display contents of data files as they are read in. This may be useful for detecting data entry errors. The default for this line is an *N.* Changing line 3 to a *Y* causes data to be displayed as they are read into the **MicroFish Statistical Package**.

Parameter 4 operates in conjunction with parameter 3. If line 3 is changed to *Y*, indicating input data should be displayed, then line 4 controls the output destination. The default of *scrn:* in line 4 routes displayed data to the screen. Changing line 4 to *lpt1:* routes the output to the line printer. Changing line 4 to *data-in.lst* (or any other valid file name) directs output to a DOS file.

Parameter 5 stops the maximum-likelihood estimator from going into an infinite loop caused by a severely nondescending number of fish captured on subsequent electrofishing passes. The default of 5 stops the population estimate at five times the total catch.

Parameter 6 operates in conjunction with parameter 5. If the population estimate calculation is terminated then the population estimate is arbitrarily reset to 1.5 (the default value) times the total catch. Parameter 6 should be less than parameter 5.

To illustrate, assume the total catch equals 100 fish and parameters 5 and 6 are at their default values of 5 and 1.5, respectively. If a nondescending removal pattern of fish had taken place, the population estimate calculation would be terminated at 5 times the total catch (500) and would be reset to 1.5 times the total catch (150).

Parameter 7 is an estimate of the maximum number of observations (lines of data) in the fish capture data file for the purpose of memory allocation in the **MicroFish Statistical Package**. If you have data sets exceeding the default value of 5,000 observations, then a "Subscript out of range" error will result. In this case, simply change parameter 7 to a higher number than the actual number of observations encountered.

FISH CAPTURE DATA FILE

Fish capture data files are designed to be as simple as possible, patterned after an electrofishing tally sheet. Detailed data instructions are given below. Perhaps the quickest way to learn the data configuration, however, is to look at the sample file provided (see appendix 4). The example file of fish capture data is called MF-TEST.DAT.

Setting Up Fish Capture Data

First Line of Data—This line (called the header record) should contain study area information necessary to distinguish this data set from others. The information will appear on table form output (from MFISH.EXE), but not in database files (created by MFISH-DB.EXE). Three examples are below:

So. Fk. Salmon River, Idaho, 5/12/88
Rush Creek, CA. Fall, 1988
Third study area, test data

After the header record, subsequent lines of data pertain to captured fish. If individual fish are weighed and measured during electrofishing, then each line (record) in the data set corresponds to an individual fish. Generally, five variables (fields) are expected on each line of data. If fish are counted and weighed in groups then two additional fields are required. If no fish are caught on an electrofishing pass then only three fields are required.

Variable 1. The Site Number—This is the number of the site where the fish was captured. It must be an integer from 1 to the maximum number of sites in sequential order (don't skip numbers). That is, if only one study site is being analyzed in the data set, then the number 1 must be present throughout the length of the data file. If three study sites were electrofished, then **MicroFish** expects the numbers 1, 2, and 3 to be present somewhere in the first column of data.

Variable 2. The Electrofishing Pass Number—If four electrofishing passes were made, then this number would be a 1, 2, 3, or 4, depending on which electrofishing pass the fish was caught.

Variable 3. The Species Number—A species number should be entered here to identify the fish captured. Valid species numbers are from 1 to 1,000. Each species number must correspond to a fish name listed in the file MF-FISH.DAT. Note that species numbers in the sample fish capture data file MF-TEST.DAT (appendix 4) are 2, 3, 10, and 11, corresponding to Rainbow Trout, Brook Trout, etc., from the file of fish names, MF-FISH.DAT. If no fish were caught on the electrofishing pass, enter a 0 for species number and leave the remaining variables blank. (Actually, this last case is required only when the pass is the last in a series of removals, such as the third of three passes.)

Variable 4. The Fish Length—If a value exists, millimeters are expected. (Any units can be used for length and weight, but condition factors will be valid only with millimeters for length and grams for weight, the way the program is set up.)

Variable 5. The Fish Weight—If a value exists, grams are expected.

[Variables 6 and 7 are optional. If for some reason each individual fish was not weighed and measured, then the option of group analysis exists. A unique group must be defined for each species encountered on each electrofishing pass. If individual measurements were performed, these variables can be left blank.]

Variable 6. The Total Number of Fish Captured—If this option is used then variables 4 and 5 must contain periods instead of length and weight measurements. Periods signify missing values.

Variable 7. The Total Weight of Fish Captured—If this option is used then variables 4 and 5 must contain periods instead of length and weight measurements. If neither group weights nor individual weights were taken then put a period in the place of variable 7.

Examples of Fish Capture Data

The following examples illustrate the four allowable types of data lines (not counting the header record):

```
Line 1 ⇒    1    1     3    100    15.1
Line 2 ⇒    2    2    10     .       .     3    16.8
Line 3 ⇒    3    2    11     .       .     2      .
Line 4 ⇒    3    4     0
```

Line 1 identifies a fish captured from study site 1 on the first electrofishing pass. The species number of 3 indicates from file MF-FISH.DAT that a brook trout was captured. The fish was 100 millimeters in length and weighed 15.1 grams.

Line 2 refers to a group of fish captured. Note that variables 4 and 5 contain periods indicating missing values (no individual fish measurements). This group of fish was captured from study site 2 on the second electrofishing pass. Species number of 10 refers to suckers according to file MF-FISH.DAT. Three suckers were captured with a group weight of 16.8 grams.

Line 3 identifies fish captured in study site 3 on the second electrofishing pass. Species number 11 refers to sculpin. Two fish were captured. No group weight was taken.

Line 4 represents a special situation. In study site 3 on electrofishing pass 4 no fish were captured. In such cases a zero should be entered for the species number. No length and weight information should be entered. A species number of zero is the only species number that will not have a corresponding species name in the file of fish names, MF-FISH.DAT. This special record type is only required when no fish are caught in the entire study area on the last of a series of removals (it signals to **MicroFish** how many electrofishing passes were made).

Notes on Fish Capture Data

Note 1. Data Delimiters—All variables need to be separated by at least one blank space (or a comma, or both). Do not put blank lines in the data.

Note 2. Mixing Individual and Group Measurements—The **MicroFish Statistical Package** is not capable of performing calculations on a data set in which a single species has a mixture of individually weighed fish and fish weighed in groups. Species A may have grouped measurements and Species B may have individual fish measurements in the same data set, but don't mix individuals and groups within the same species.

Note 3. Number of Electrofishing Passes—The **MicroFish Statistical Package** is capable of comparing several study sites within a study area. The same number of electrofishing passes must be made at each site in a data set. The largest electrofishing pass number in the data is assumed to be the number of passes at each site.

Program Output

OUTPUT: TABLE FORMAT

MFISH.EXE is capable of outputting fisheries population estimates and statistics in tabular form to the screen, to a line printer, or to a data file. (See appendix 2.)

OUTPUT: DATA-BASE FORMAT

MFISH-DB.EXE creates output data files only. Output files can be sent to any disk drive or directory designated by the user. The following file definition describes the output format from program MFISH-DB.EXE:

Field name	Starting column	Ending column	Field length	Data type
Data file Name	1	12	12	Character
Variable Sort Field	14	15	2	Numeric
Species Sort Field	16	17	2	Numeric
Variable Name	19	30	12	Character
Removal Number	32	32	1	Numeric
Species Name	34	49	16	Character
Overall Value	50	59	10	Numeric
Site 1 Value	60	69	10	Numeric
Site 2 Value	70	79	10	Numeric
Site 3 Value	80	89	10	Numeric

There will be a minimum of one site listed in the output. The output will vary in length, depending on the number of sites sampled. Each site adds 10 characters to the output record length. (See appendix 3.)

OUTPUT FILE EXTENSIONS FROM MFISH-DB.EXE

All MFISH-DB.EXE output results are automatically given a ".RES" file name extension. For example, if a file named FISH1988.DAT is used as input then the results file will be labeled FISH1988.RES.

PROCESSING MULTIPLE DATA FILES WITH MFISH-DB.EXE

MFISH-DB.EXE allows one to process several data sets at once or one at a time. If processing several data sets, a file must be created containing a list of data file names. The data in this list will be processed sequentially. For example, assume the file FISHDATA.LST contains a list of the following fish data files that reside in the DAT87 and DAT88 directories on the C: disk drive:

```
C:\DAT87\F87-IDAH.DAT
C:\DAT87\F87-OREG.DAT
C:\DAT87\F87-WASH.DAT
C:\DAT88\F88-IDAH.DAT
C:\DAT88\F88-OREG.DAT
C:\DAT88\F88-WASH.DAT
```

When MFISH-DB prompts

```
1—Run one data set
2—Run more than one data set
```

press "2". The user is then prompted

```
Enter the name of the file
containing data file names:
```

Now type *FISHDATA.LST <enter>*, or whatever name you've chosen for the file you created with the list of fish data file names. Output for all six files will be generated.

[Hint: To facilitate creation of data file lists use a DOS "piping" command. For example, typing *DIR *.DAT > FISHDATA.LST* creates a file called FISHDATA.LST consisting of all files with a ".DAT" extension. Use an editor to "clean up" nonessential information from this newly created list of data file names.]

Tips for Efficient Program Operation

BYPASSING DIPSLAY SCREENS

Display screens in programs MFISH.EXE and MFISH-DB.EXE can be bypassed by pressing the *ESC*ape key at the initial title page.

ACCESSING DISK DRIVES AND DIRECTORIES

Specification of PATH calls preceding input or output file names allows the user to retrieve or send data to selected disk drives or directories. For example:

```
Input  data file:  A:FISH.DAT
Output data file:  C:\OUTPUT\RESULTS.88
```

In this example the input file FISH.DAT is read from disk drive A. The output file RESULTS.88 is sent to the OUTPUT directory on disk drive C. In the case of database output (from program MFISH-DB.EXE) only the output directory should be specified because file name extensions (".RES") are automatically assigned.

Commonly Asked Questions

Q: *Does data in the fish capture data file need to be in any order?*
A: No, as long as the header record is the first line in the data.

Q: *Can species be subdivided by age-groups?*
A: Yes, the species file MF-FISH.DAT can be set up any way the user desires. Simply change the fish file species codes and descriptions to accommodate your needs. Don't forget to change the species codes in the fish capture data file to their new values. It may be preferable to copy the old fish capture data file to a new file. Then, change the species codes in the new file.

Example: Suppose you ran the **MicroFish Statistical Package** on a data file that only contained rainbow trout (species code 2 according to the original values). After scanning the data, you realize that clear age-class breaks can be made at 100 and 200 mm. The following three species codes might be added to the MF-FISH.DAT data file:

```
20, "RBT < 100 mm"
21, "RBT 100-200 mm"
22, "RBT > 200 mm"
```

Once these new species codes are established in MF-FISH.DAT, the fish capture data should be modified to reflect these changes. Rerun the **MicroFish Statistical Package** to produce population statistics by age class.

Q: *How do I compare the same study area over a period of 4 years?*
A: Define each year's data as a particular site. For example, this year's data would be considered site 4, last year's data would be site 3, etc.

Q: *I didn't collect lengths or weights. How do I process my data?*
A: Lengths and weights are not required. In such cases, use the format of example Line 3 where individual length and weight and group weight have missing values. A group total of 1 is permissible.

Q: *How can I summarize my fisheries data by date, location, or species?*
A: Combine all the necessary database files (output from MFISH-DB.EXE) into one large file. If data file names (which are included on each line of output) have been consistently set up to include year and study area, then one can sort on the appropriate fields to organize data by year, location, and species. An example data

file naming convention is F88-AREA.DAT where F refers to fisheries data (as opposed to H for habitat, S for sediment, etc.), 88 refers to the year, and AREA is a four character designation for the sampling location.

MICROFISH SAMPLE SIZE PROGRAMS

Purpose

The sample size software (programs MF-SS2D.EXE and MF-SS3D.EXE) answers the question of how many electrofishing passes are required to yield desired levels of precision in the maximum-likelihood population estimate. It is assumed that electrofishing is performed using removal-depletion sampling.

A more complete paper, which discusses the interrelationships among population size (N), catchability (P), population estimate precision, and the number of electrofishing passes (T), is currently in preparation.

Definitions

Catchability is defined as the proportion of fish captured on a given electrofishing pass (for example, each electrofishing pass captures 50 percent of the fish remaining in the stream).

Precision is described in terms of the coefficient of precision, CP(N), a statistic developed by the authors for ease of use. The value associated with the coefficient of precision indicates that the true population size is within a given percentage of the population estimate. Therefore, if the coefficient of precision is 10, then the true population size is within 10 percent of the sample estimate at the 95 percent confidence level. If $N = 500$ and $\text{CP}(500) = 10$ then the 95 percent confidence limits around N would equal 450 and 550, respectively.

Introduction

There are two **MicroFish** programs for assessing and understanding electrofishing sample size requirements for population estimation. Computer graphics capabilities are required for both programs.

The first program, MF-SS2D.EXE, shows sample size relationships among N, P, T, and CP(N) in two dimensions (2-D). The graph generated by this program has labeled axes and is suitable for field use.

The second program, MF-SS3D.EXE, displays sample size relationships in three-dimensional (3-D) format to provide an improved conceptual understanding of the relationships among N, P, T, and CP(N). Although no axis labels are provided, the X axis refers to population estimate, the Y axis represents catchability, and the Z axis identifies the coefficient of precision reached by successive electrofishing passes.

Printing

To print graphs from the computer screen, one must type in the word *GRAPHICS* (a DOS command) before running the program, then press the Print-Screen key once the graph is displayed.

Adaptability

The graphics are flexible such that the range of parameters [N, P, T, and CP(N)] can be adjusted to investigate all possible relationships. Color parameters in the software are also adjustable. To change these parameters simply modify the sample size files, MF-SS2D.FIL and MF-SS3D.FIL. These files are automatically read by the corresponding sample size program each time a program is run.

Adjustable Parameters: MicroFish Sample Size Graph (2-D)

The following is an example of MF-SS2D.FIL:

```
50   350   50
30    70    5
 2     6    1
50     1   10    1
 9     1    3    2    1
```

Line 1 sets the range of population estimates from 50 to 350 in increments of 50. Line 2 sets catchability from 30 percent to 70 percent in 5 percent increments. Line 3 sets the number of electrofishing passes from 2 to 6 in increments of 1 (two passes minimum are required).

Parameter 1 of Line 4 sets the maximum CP(*N*) at 50. Parameter 2 should equal 1 to display CP(*N*) scales, zero to suppress scales. Parameter 3 sets the number of increments to be made on the CP(*N*) scale. In the case shown above, precision levels up to CP(*N*) = 50 will be shown in 10 increments (0, 5, 10, ..., 50). Parameter 4 displays precision lines behind display bars if the parameter value is 1. These lines are suppressed if parameter 4 is 0.

On Line 5, parameter 1 sets the background color (text mode) for the axis labels. Parameters 2 through 5 set the colors (graphics mode) for palette, graph background color, border color, and scale line color, respectively. Graphics mode colors range from 0 to 3. Refer to an IBM (or compatible) Basic manual.

Adjustable Parameters: MicroFish Sample Size Graph (3-D)

The following is an example of MF-SS3D.FIL:

```
50   300   50
25    75    5
 2     6    1
50
 9     0    3
```

The MF-SS3D.FIL is exactly analogous, except that fewer adjustable parameters are present in line 4. Line 5 lists background color, palette, and line color.

Assessing Sampling Requirements

To estimate electrofishing sample size it is necessary to make rough predictions of *N* and *P* and to choose a desired precision level. The likelihood of meeting precision goals during actual sampling will be increased if the estimates for *N* and *P* are conservative (lower than the true values).

If one species of the sampled population is of particular interest, the values of *N* and *P* for that individual species should be used when determining the number of electrofishing passes needed.

Sample size graphs are displayed with several groups of columns, one group for each population estimate. Each group of columns represents the range of catchabilities specified by the user. Find the most appropriate values of *N* and *P* on the graph, then proceed vertically up the column until you reach the desired precision level listed on the left-hand axis. The color of the bar at that point indicates the number of electrofishing passes required to reach that precision level given the values of *N* and *P*. This is the number of electrofishing passes that should be made in the field.

MICROFISH VERSION 3.0 ENHANCEMENTS

1. The **MicroFish Statistical Package (Database Format)**, MFISH-DB.EXE, enables **MicroFish** output to be readily used by other commercial packages. In effect, the output from MFISH-DB.EXE can be imported directly into graphics packages, database managers, spreadsheets, etc.

2. MFISH-DB.EXE permits multiple data file processing.

3. Biomass calculations are performed. Relative percentages of biomass are calculated by species and site.

4. The database format facilitates output file management, file integration, and file coordination.

MICROFISH TECHNICAL NOTES

MicroFish programs perform maximum-likelihood population estimates based on the number of fish captured on each electrofishing pass (Van Deventer and Platts 1983). Under certain circumstances a maximum-likelihood calculation is not possible (see the Error Handling section).

Values of the Student's *t* distribution used in confidence intervals are taken to 3 decimal places for 100 and fewer degrees of freedom; 2 decimal places for less than 100 degrees of freedom. When the population estimate lower confidence interval is less than the total catch, the lower CI is set equal to the total catch. In this case the **MicroFish Interactive Program** will issue a message. The **MicroFish Statistical Package** will not.

The DOS operating system provides three key sequences that are useful with any program:

Cntl-NumLock—These two keys pressed simultaneously halt the "scrolling" of information on the screen. Pressing any key resumes the scrolling.

Cntl-Break—Terminates program execution at any time.

Alt-Cntl-Del—Terminates all operations and reboots the computer.

ERROR HANDLING

Population Estimate Errors

Maximum-likelihood estimation is not possible in four situations:

1. if a total of 1 fish is caught on all passes,
2. if all fish are caught on the first pass,
3. if there is a severely nondescending removal pattern, or
4. if no fish were caught in the sampling site.

The **MicroFish Statistical Package (Database Format)** will list error numbers in the output file. The **MicroFish Statistical Package (Table Format)** will display the following error messages on the screen when a maximum-likelihood population estimate cannot be calculated:

1 No maximum likelihood estimate generated. Reason: only 1 fish caught in all removals.

2 No maximum likelihood estimate generated. Reason: all fish caught on first pass.

3 Maximum likelihood estimate terminated at 5 times the total catch. Estimate has been arbitrarily reset to 1.5 times the total catch according to MF-PARM.DAT. Population estimate termination was caused by a nondescending removal pattern. Results should not be considered reliable.

4 No maximum likelihood estimate generated. Reason: no fish captured.

In the first, second, and fourth cases the population estimate is set equal to the total catch. Statistics associated with capture probability are set to zero. How **MicroFish** handles the third case is discussed in the "PARAMETER FILE (MF-PARM.DAT)" section of the user's guide (see parameters 5 and 6).

Two of these situations are illustrated by running the example data, MF-TEST.DAT, where removal patterns are flagged and warning messages are issued.

Out of Memory Errors

An "out of memory" error will occur if your computer doesn't have enough memory for both the program and the data. If you have a RAM disk or any other memory-resident modules, reboot your computer without loading them. If that doesn't work, reduce parameter 7 in the MF-PARM.DAT file from the default value of 5,000 down to the number of data lines your fish capture data actually have and rerun the **MicroFish Statistical Package.**

Other Errors

Data entry errors and improper data formatting are the two biggest problems encountered by **MicroFish** users. Should you encounter an error, try the diagnostic aids recommended in the "PARAMETER FILE (MF-PARM.DAT)" section. Also, sort a copy of your data and check for (1) non-sequential assignment of site numbers (other than 1, 2, 3, etc.), (2) species weights of zero, and (3) mixture of individual and grouped measurements within a single species. Any of these three conditions will cause the program to terminate.

If all else fails, contact the authors for help.

REFERENCES

Van Deventer, J. S.; Platts, W. S. 1983. Sampling and estimating fish populations from streams. Transactions of the North American Wildlife and Natural Resources Conference. 48: 349-354.

Van Deventer, J. S.; Platts, W. S. 1985. A computer software system for entering, managing, and analyzing fish capture data from streams. Res. Note INT-352. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p.

APPENDIX 1: OUTPUT EXAMPLE FROM THE MICROFISH INTERACTIVE PROGRAM (MF. EXE)

```
Stream:  South Fork Salmon River
Species:  Rainbow Trout

Removal Pattern:   124  61  35  14
Total Catch             =   234
Population Estimate     =   249

Chi Square              =     0.675
Pop Est Standard Err    =     6.164
Lower Conf Interval     =   236.858
Upper Conf Interval     =   261.142

Capture Probability     =     0.501
Capt Prob Standard Err  =     0.035
Lower Conf Interval     =     0.432
Upper Conf Interval     =     0.570
```

APPENDIX 2: OUTPUT EXAMPLE FROM THE MICROFISH STATISTICAL PACKAGE (MFISH.EXE)

```
FISH SAMPLING RESULTS

TITLE:  MICROFISH TEST DATA                          Number of Sites    =  3
FILE:   mf-test.dat                                  Number of Removals =  4
DATE:   09-07-88    1:28 p.m.                        Number of Species  =  4



                         REMOVAL PATTERNS

    SPECIES          SITE       RMVL 1  RMVL 2  RMVL 3  RMVL 4

  Trout: Rainbow      1           11       5       3       2
  Trout: Rainbow      2            6       5       2       1
  Trout: Rainbow      3           13       7       5       2
  Trout: Brook        1           22       7       6       3
  Trout: Brook        2           18      11       6       3
  Trout: Brook        3           20      12       4       4
  Sucker              1           19      11       6       2
  Sucker              2            4       2       0       1
  Sucker              3            6       3       3       1
  Sculpin             1           12       7       3       0
*2* Sculpin           2            4       0       0       0
*3* Sculpin           3            3       2       5       5

  Trout: Rainbow   All Sites      30      17      10       5
  Trout: Brook     All Sites      60      30      16      10
  Sucker           All Sites      29      16       9       4
  Sculpin          All Sites      19       9       8       5

  All Species         1           64      30      18       7
  All Species         2           32      18       8       5
  All Species         3           42      24      17      12

  All Species      All Sites     138      72      43      24

WARNING

*2*  No maximum likelihood estimate generated.
     Reason:  all fish caught on 1st pass.

*3*  Maximum likelihood estimate terminated at 5
     times the total catch.  Estimate has been
     arbitrarily reset to 1.5  times the
     total catch according to MF-PARM.DAT.
     Population estimate termination was caused by
     a non-descending removal pattern.  Results
     should not be considered reliable.
```

APPENDIX 2: (Con.)

FISH CAPTURE TOTALS (% by Species)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	#FISH	%	#FISH	%	#FISH	%	#FISH	%
Trout: Rainbow	21	33.9%	14	22.6%	27	43.5%	62	100.0%
Trout: Brook	38	32.8%	38	32.8%	40	34.5%	116	100.0%
Sucker	38	65.5%	7	12.1%	13	22.4%	58	100.0%
Sculpin	22	53.7%	4	9.8%	15	36.6%	41	100.0%
TOTAL	119	43.0%	63	22.7%	95	34.3%	277	100.0%

FISH CAPTURE TOTALS (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	#FISH	%	#FISH	%	#FISH	%	#FISH	%
Trout: Rainbow	21	17.6%	14	22.2%	27	28.4%	62	22.4%
Trout: Brook	38	31.9%	38	60.3%	40	42.1%	116	41.9%
Sucker	38	31.9%	7	11.1%	13	13.7%	58	20.9%
Sculpin	22	18.5%	4	6.3%	15	15.8%	41	14.8%
TOTAL	119	100.0%	63	100.0%	95	100.0%	277	100.0%

POPULATION ESTIMATES (% by Species)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL		
	EST	%	EST	%	EST	%	TOTAL	%	EST
Trout: Rainbow	22	33.8%	14	21.5%	29	44.6%	65	100%	67
Trout: Brook	39	32.0%	41	33.6%	42	34.4%	122	100%	125
Sucker	40	65.6%	7	11.5%	14	23.0%	61	100%	62
Sculpin	22	44.9%	4	8.2%	23	46.9%	49	100%	47
SITE ESTIMATES	126	41.2%	67	21.9%	113	36.9%	306	100%	305

APPENDIX 2: (Con.)

POPULATION ESTIMATES (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	EST	%	EST	%	EST	%	EST	%
Trout: Rainbow	22	17.9%	14	21.2%	29	26.9%	67	22.3%
Trout: Brook	39	31.7%	41	62.1%	42	38.9%	125	41.5%
Sucker	40	32.5%	7	10.6%	14	13.0%	62	20.6%
Sculpin	22	17.9%	4	6.1%	23	21.3%	47	15.6%
ESTIMATE TOTALS	123	100.0%	66	100.0%	108	100.0%	301	100.0%
SITE ESTIMATES	126		67		113		305	

POPULATION ESTIMATE STANDARD ERRORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	1.844	1.154	2.631	4.071
Trout: Brook	1.873	3.170	2.548	5.132
Sucker	2.385	0.612	2.038	3.439
Sculpin	0.802	0.000	0.000	5.417
SITE STD ERROR	4.183	3.381	10.016	9.561

POPULATION ESTIMATE 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
Trout: Rainbow	21,	26	14,	16	27,	34	62,	75
Trout: Brook	38,	43	38,	47	40,	47	116,	135
Sucker	38,	45	7,	8	13,	18	58,	69
Sculpin	22,	24	4,	4	0,	0	41,	58
SITE ESTIMATES	119,	134	63,	74	95,	133	286,	324

APPENDIX 2: (Con.)

CAPTURE PROBABILITIES

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	0.5000	0.5385	0.4655	0.4627
Trout: Brook	0.5429	0.4634	0.5000	0.4754
Sucker	0.5067	0.5833	0.4483	0.4833
Sculpin	0.6286	0.0000	0.0000	0.3905
SITE TOTAL	0.5085	0.4922	0.3640	0.4475

CAPTURE PROBABILITY STANDARD ERROR

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	0.1186	0.1416	0.1081	0.0714
Trout: Brook	0.0844	0.0912	0.0858	0.0514
Sucker	0.0872	0.1895	0.1593	0.0722
Sculpin	0.1012	0.0000	0.0000	0.0946
SITE CAPT S.E.	0.0490	0.0686	0.0636	0.0342

CAPTURE PROBABILITY 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	0.2534, 0.7466	0.2326, 0.8443	0.2442, 0.6869	0.3201, 0.6052
Trout: Brook	0.3721, 0.7136	0.2792, 0.6476	0.3267, 0.6733	0.3737, 0.5771
Sucker	0.3303, 0.6830	0.1195, 1.0471	0.1043, 0.7923	0.3390, 0.6277
Sculpin	0.4180, 0.8392	0.0000, 0.0000	0.0000, 0.0000	0.2001, 0.5809
SITE 95% C.I.	0.4115, 0.6056	0.3551, 0.6292	0.2380, 0.4899	0.3802, 0.5148

APPENDIX 2: (Con.)

CHI SQUARE GOODNESS OF FIT

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	0.3591	1.1960	0.3708	0.1757
Trout: Brook	1.8203	0.1731	1.2897	0.2947
Sucker	0.4914	2.4504	0.7051	0.1809
Sculpin	2.2600	0.0000	0.0000	0.8322
SITE TOTAL	0.5315	0.2636	0.3971	0.2562

CONDITION FACTORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	1.320	1.126	1.346	1.288
Trout: Brook	1.232	1.331	1.197	1.252

AVERAGE LENGTHS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	77.9	86.8	70.4	76.7
Trout: Brook	87.0	90.3	72.6	83.1

LENGTH STANDARD DEVIATIONS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	31.278	40.971	30.719	33.494
Trout: Brook	36.610	34.146	33.927	35.459

LENGTH 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	63.7, 92.1	63.1, 110.4	58.3, 82.6	68.2, 85.2
Trout: Brook	75.0, 99.1	79.1, 101.6	61.8, 83.5	76.6, 89.7

APPENDIX 2: (Con.)

TOTAL WEIGHTS (% by Species)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	WEIGHT	%	WEIGHT	%	WEIGHT	%	WEIGHT	%
Trout: Rainbow	188	33.3%	183	32.5%	193	34.2%	565	100.0%
Trout: Brook	474	35.7%	527	39.7%	326	24.5%	1327	100.0%
Sucker	230	66.5%	35	10.2%	81	23.3%	347	100.0%
TOTAL	893	39.9%	746	33.3%	600	26.8%	2238	100.0%

TOTAL WEIGHTS (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	WEIGHT	%	WEIGHT	%	WEIGHT	%	WEIGHT	%
Trout: Rainbow	188	21.1%	183	24.6%	193	32.2%	565	25.2%
Trout: Brook	474	53.1%	527	70.7%	326	54.3%	1327	59.3%
Sucker	230	25.8%	35	4.7%	81	13.5%	347	15.5%
TOTAL	893	100.0%	746	100.0%	600	100.0%	2238	100.0%

AVERAGE WEIGHTS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	9.0	13.1	7.2	9.1
Trout: Brook	12.5	13.9	8.1	11.4
Sucker	6.1	5.0	6.2	6.0

WEIGHT STANDARD DEVIATIONS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	9.126	16.036	10.996	11.790
Trout: Brook	13.525	17.416	16.030	15.801

WEIGHT 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Trout: Rainbow	4.8, 13.1	3.8, 22.4	2.8, 11.5	6.1, 12.1
Trout: Brook	8.0, 16.9	8.1, 19.6	3.0, 13.3	8.5, 14.3

ESTIMATED BIOMASS (% by Spec)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	BIOMASS	%	BIOMASS	%	BIOMASS	%	BIOMASS	%
Trout: Rainbow	197	33.5%	183	31.2%	208	35.3%	588	100.0%
Trout: Brook	487	34.8%	568	40.7%	342	24.5%	1397	100.0%
Sucker	243	66.5%	35	9.6%	87	23.8%	365	100.0%
TOTAL	926	39.4%	787	33.5%	637	27.1%	2350	100.0%

ESTIMATED BIOMASS (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	BIOMASS	%	BIOMASS	%	BIOMASS	%	BIOMASS	%
Trout: Rainbow	197	21.3%	183	23.3%	208	32.6%	588	25.0%
Trout: Brook	487	52.5%	568	72.2%	342	53.7%	1397	59.5%
Sucker	243	26.2%	35	4.5%	87	13.7%	365	15.5%
TOTAL	926	100.0%	787	100.0%	637	100.0%	2350	100.0%

APPENDIX 3: OUTPUT EXAMPLE FROM THE MICROFISH STATISTICAL PACKAGE (MFISH-DB.EXE)

```
MF-TEST .DAT  1 0 Fish Removal 1 ALL SPECIES      138      64      32      42
MF-TEST .DAT  1 0 Fish Removal 2 ALL SPECIES       72      30      18      24
MF-TEST .DAT  1 0 Fish Removal 3 ALL SPECIES       43      18       8      17
MF-TEST .DAT  1 0 Fish Removal 4 ALL SPECIES       24       7       5      12
MF-TEST .DAT  1 1 Fish Removal 1 Trout: Rainbow    30      11       6      13
MF-TEST .DAT  1 1 Fish Removal 2 Trout: Rainbow    17       5       5       7
MF-TEST .DAT  1 1 Fish Removal 3 Trout: Rainbow    10       3       2       5
MF-TEST .DAT  1 1 Fish Removal 4 Trout: Rainbow     5       2       1       2
MF-TEST .DAT  1 2 Fish Removal 1 Trout: Brook      60      22      18      20
MF-TEST .DAT  1 2 Fish Removal 2 Trout: Brook      30       7      11      12
MF-TEST .DAT  1 2 Fish Removal 3 Trout: Brook      16       6       6       4
MF-TEST .DAT  1 2 Fish Removal 4 Trout: Brook      10       3       3       4
MF-TEST .DAT  1 3 Fish Removal 1 Sucker            29      19       4       6
MF-TEST .DAT  1 3 Fish Removal 2 Sucker            16      11       2       3
MF-TEST .DAT  1 3 Fish Removal 3 Sucker             9       6       0       3
MF-TEST .DAT  1 3 Fish Removal 4 Sucker             4       2       1       1
MF-TEST .DAT  1 4 Fish Removal 1 Sculpin           19      12       4       3
MF-TEST .DAT  1 4 Fish Removal 2 Sculpin            9       7       0       2
MF-TEST .DAT  1 4 Fish Removal 3 Sculpin            8       3       0       5
MF-TEST .DAT  1 4 Fish Removal 4 Sculpin            5       0       0       5
MF-TEST .DAT  2 0 Rmvl Warning   ALL SPECIES        0       0       0       0
MF-TEST .DAT  2 1 Rmvl Warning   Trout: Rainbow     0       0       0       0
MF-TEST .DAT  2 2 Rmvl Warning   Trout: Brook       0       0       0       0
MF-TEST .DAT  2 3 Rmvl Warning   Sucker             0       0       0       0
MF-TEST .DAT  2 4 Rmvl Warning   Sculpin            0       0       2       3
MF-TEST .DAT  3 0 Fish Totals    ALL SPECIES      277     119      63      95
MF-TEST .DAT  3 1 Fish Totals    Trout: Rainbow    62      21      14      27
MF-TEST .DAT  3 2 Fish Totals    Trout: Brook     116      38      38      40
MF-TEST .DAT  3 3 Fish Totals    Sucker            58      38       7      13
MF-TEST .DAT  3 4 Fish Totals    Sculpin           41      22       4      15
MF-TEST .DAT  4 0 Fish %--Spec   ALL SPECIES      100.0    43.0    22.7    34.3
MF-TEST .DAT  4 1 Fish %--Spec   Trout: Rainbow   100.0    33.9    22.6    43.5
MF-TEST .DAT  4 2 Fish %--Spec   Trout: Brook     100.0    32.8    32.8    34.5
MF-TEST .DAT  4 3 Fish %--Spec   Sucker           100.0    65.5    12.1    22.4
MF-TEST .DAT  4 4 Fish %--Spec   Sculpin          100.0    53.7     9.8    36.6
MF-TEST .DAT  5 0 Fish %--Site   ALL SPECIES      100.0   100.0   100.0   100.0
MF-TEST .DAT  5 1 Fish %--Site   Trout: Rainbow    22.4    17.6    22.2    28.4
MF-TEST .DAT  5 2 Fish %--Site   Trout: Brook      41.9    31.9    60.3    42.1
MF-TEST .DAT  5 3 Fish %--Site   Sucker            20.9    31.9    11.1    13.7
MF-TEST .DAT  5 4 Fish %--Site   Sculpin           14.8    18.5     6.3    15.8
MF-TEST .DAT  6 0 Pop Estimate   ALL SPECIES      305     126      67     113
MF-TEST .DAT  6 1 Pop Estimate   Trout: Rainbow    67      22      14      29
MF-TEST .DAT  6 2 Pop Estimate   Trout: Brook     125      39      41      42
MF-TEST .DAT  6 3 Pop Estimate   Sucker            62      40       7      14
MF-TEST .DAT  6 4 Pop Estimate   Sculpin           47      22       4      23
MF-TEST .DAT  7 0 Est %--Spec    ALL SPECIES      100.0    41.2    21.9    36.9
MF-TEST .DAT  7 1 Est %--Spec    Trout: Rainbow   100.0    33.8    21.5    44.6
MF-TEST .DAT  7 2 Est %--Spec    Trout: Brook     100.0    32.0    33.6    34.4
MF-TEST .DAT  7 3 Est %--Spec    Sucker           100.0    65.6    11.5    23.0
MF-TEST .DAT  7 4 Est %--Spec    Sculpin          100.0    44.9     8.2    46.9
MF-TEST .DAT  8 0 Est %--Site    ALL SPECIES      100.0   100.0   100.0   100.0
MF-TEST .DAT  8 1 Est %--Site    Trout: Rainbow    22.3    17.9    21.2    26.9
MF-TEST .DAT  8 2 Est %--Site    Trout: Brook      41.5    31.7    62.1    38.9
MF-TEST .DAT  8 3 Est %--Site    Sucker            20.6    32.5    10.6    13.0
```

APPENDIX 3: (Con.)

```
MF-TEST .DAT  8 4 Est %--Site    Sculpin            15.6     17.9      6.1      21.3
MF-TEST .DAT  9 0 Est Std Err    ALL SPECIES         9.561    4.183    3.381   10.016
MF-TEST .DAT  9 1 Est Std Err    Trout: Rainbow      4.071    1.844    1.154    2.631
MF-TEST .DAT  9 2 Est Std Err    Trout: Brook        5.132    1.873    3.170    2.548
MF-TEST .DAT  9 3 Est Std Err    Sucker              3.439    2.385    0.612    2.038
MF-TEST .DAT  9 4 Est Std Err    Sculpin             5.417    0.802    0.000    0.000
MF-TEST .DAT 10 0 Est Lower CI   ALL SPECIES       286      119       63       95
MF-TEST .DAT 10 1 Est Lower CI   Trout: Rainbow     62       21       14       27
MF-TEST .DAT 10 2 Est Lower CI   Trout: Brook      116       38       38       40
MF-TEST .DAT 10 3 Est Lower CI   Sucker             58       38        7       13
MF-TEST .DAT 10 4 Est Lower CI   Sculpin            41       22        4        0
MF-TEST .DAT 11 0 Est Upper CI   ALL SPECIES       324      134       74      133
MF-TEST .DAT 11 1 Est Upper CI   Trout: Rainbow     75       26       16       34
MF-TEST .DAT 11 2 Est Upper CI   Trout: Brook      135       43       47       47
MF-TEST .DAT 11 3 Est Upper CI   Sucker             69       45        8       18
MF-TEST .DAT 11 4 Est Upper CI   Sculpin            58       24        4        0
MF-TEST .DAT 12 0 Capt Prob      ALL SPECIES         0.447    0.509    0.492    0.364
MF-TEST .DAT 12 1 Capt Prob      Trout: Rainbow      0.463    0.500    0.538    0.466
MF-TEST .DAT 12 2 Capt Prob      Trout: Brook        0.475    0.543    0.463    0.500
MF-TEST .DAT 12 3 Capt Prob      Sucker              0.483    0.507    0.583    0.448
MF-TEST .DAT 12 4 Capt Prob      Sculpin             0.390    0.629    0.000    0.000
MF-TEST .DAT 13 0 Capt Prob SE   ALL SPECIES         0.034    0.049    0.069    0.064
MF-TEST .DAT 13 1 Capt Prob SE   Trout: Rainbow      0.071    0.119    0.142    0.108
MF-TEST .DAT 13 2 Capt Prob SE   Trout: Brook        0.051    0.084    0.091    0.086
MF-TEST .DAT 13 3 Capt Prob SE   Sucker              0.072    0.087    0.190    0.159
MF-TEST .DAT 13 4 Capt Prob SE   Sculpin             0.095    0.101    0.000    0.000
MF-TEST .DAT 14 0 C P Lower CI   ALL SPECIES         0.380    0.412    0.355    0.238
MF-TEST .DAT 14 1 C P Lower CI   Trout: Rainbow      0.320    0.253    0.233    0.244
MF-TEST .DAT 14 2 C P Lower CI   Trout: Brook        0.374    0.372    0.279    0.327
MF-TEST .DAT 14 3 C P Lower CI   Sucker              0.339    0.330    0.120    0.104
MF-TEST .DAT 14 4 C P Lower CI   Sculpin             0.200    0.418    0.000    0.000
MF-TEST .DAT 15 0 C P Upper CI   ALL SPECIES         0.515    0.606    0.629    0.490
MF-TEST .DAT 15 1 C P Upper CI   Trout: Rainbow      0.605    0.747    0.844    0.687
MF-TEST .DAT 15 2 C P Upper CI   Trout: Brook        0.577    0.714    0.648    0.673
MF-TEST .DAT 15 3 C P Upper CI   Sucker              0.628    0.683    1.047    0.792
MF-TEST .DAT 15 4 C P Upper CI   Sculpin             0.581    0.839    0.000    0.000
MF-TEST .DAT 16 0 Chi Square     ALL SPECIES         0.256    0.532    0.264    0.397
MF-TEST .DAT 16 1 Chi Square     Trout: Rainbow      0.176    0.359    1.196    0.371
MF-TEST .DAT 16 2 Chi Square     Trout: Brook        0.295    1.820    0.173    1.290
MF-TEST .DAT 16 3 Chi Square     Sucker              0.181    0.491    2.450    0.705
MF-TEST .DAT 16 4 Chi Square     Sculpin             0.832    2.260    0.000    0.000
MF-TEST .DAT 17 1 Cond Factor    Trout: Rainbow      1.288    1.320    1.126    1.346
MF-TEST .DAT 17 2 Cond Factor    Trout: Brook        1.252    1.232    1.331    1.197
MF-TEST .DAT 18 1 Avg Length     Trout: Rainbow     76.661   77.905   86.786   70.444
MF-TEST .DAT 18 2 Avg Length     Trout: Brook       83.147   87.026   90.342   72.625
MF-TEST .DAT 19 1 Len Std Dev    Trout: Rainbow     33.494   31.278   40.971   30.719
MF-TEST .DAT 19 2 Len Std Dev    Trout: Brook       35.459   36.610   34.146   33.927
MF-TEST .DAT 20 1 Len Lower CI   Trout: Rainbow     68.154   63.667   63.134   58.290
MF-TEST .DAT 20 2 Len Lower CI   Trout: Brook       76.628   74.994   79.120   61.773
MF-TEST .DAT 21 1 Len Upper CI   Trout: Rainbow     85.169   92.142  110.438   82.599
MF-TEST .DAT 21 2 Len Upper CI   Trout: Brook       89.665   99.059  101.565   83.477
MF-TEST .DAT 22 0 Total Weight   ALL SPECIES      2238.1    892.8    745.6    599.7
MF-TEST .DAT 22 1 Total Weight   Trout: Rainbow    564.8    188.0    183.5    193.3
MF-TEST .DAT 22 2 Total Weight   Trout: Brook     1326.8    474.3    526.9    325.6
```

APPENDIX 3: (Con.)

```
MF-TEST .DAT 22 3 Total Weight   Sucker             346.5     230.5     35.2      80.8
MF-TEST .DAT 23 0 Wt % -- Spec   ALL SPECIES        100.0      39.9     33.3      26.8
MF-TEST .DAT 23 1 Wt % -- Spec   Trout: Rainbow     100.0      33.3     32.5      34.2
MF-TEST .DAT 23 2 Wt % -- Spec   Trout: Brook       100.0      35.7     39.7      24.5
MF-TEST .DAT 23 3 Wt % -- Spec   Sucker             100.0      66.5     10.2      23.3
MF-TEST .DAT 24 0 Wt % -- Site   ALL SPECIES        100.0     100.0    100.0     100.0
MF-TEST .DAT 24 1 Wt % -- Site   Trout: Rainbow      25.2      21.1     24.6      32.2
MF-TEST .DAT 24 2 Wt % -- Site   Trout: Brook        59.3      53.1     70.7      54.3
MF-TEST .DAT 24 3 Wt % -- Site   Sucker              15.5      25.8      4.7      13.5
MF-TEST .DAT 25 0 Avg Weight     ALL SPECIES          8.1       7.5     11.8       6.3
MF-TEST .DAT 25 1 Avg Weight     Trout: Rainbow       9.1       9.0     13.1       7.2
MF-TEST .DAT 25 2 Avg Weight     Trout: Brook        11.4      12.5     13.9       8.1
MF-TEST .DAT 25 3 Avg Weight     Sucker               6.0       6.1      5.0       6.2
MF-TEST .DAT 26 1 Wt Std Dev     Trout: Rainbow      11.790     9.126   16.036    10.996
MF-TEST .DAT 26 2 Wt Std Dev     Trout: Brook        15.801    13.525   17.416    16.030
MF-TEST .DAT 27 1 Wt Lower CI    Trout: Rainbow       6.1       4.8      3.8       2.8
MF-TEST .DAT 27 2 Wt Lower CI    Trout: Brook         8.5       8.0      8.1       3.0
MF-TEST .DAT 28 1 Wt Upper CI    Trout: Rainbow      12.1      13.1     22.4      11.5
MF-TEST .DAT 28 2 Wt Upper CI    Trout: Brook        14.3      16.9     19.6      13.3
MF-TEST .DAT 29 0 Est Biomass    ALL SPECIES       2350.1     926.4    787.2     636.5
MF-TEST .DAT 29 1 Est Biomass    Trout: Rainbow     588.1     197.0    183.5     207.6
MF-TEST .DAT 29 2 Est Biomass    Trout: Brook      1397.2     486.8    568.5     341.9
MF-TEST .DAT 29 3 Est Biomass    Sucker             364.8     242.6     35.2      87.0
MF-TEST .DAT 30 0 Est Bio % Sp   ALL SPECIES        100.0      39.4     33.5      27.1
MF-TEST .DAT 30 1 Est Bio % Sp   Trout: Rainbow     100.0      33.5     31.2      35.3
MF-TEST .DAT 30 2 Est Bio % Sp   Trout: Brook       100.0      34.8     40.7      24.5
MF-TEST .DAT 30 3 Est Bio % Sp   Sucker             100.0      66.5      9.6      23.8
MF-TEST .DAT 31 0 Est Bio % Si   ALL SPECIES        100.0     100.0    100.0     100.0
MF-TEST .DAT 31 1 Est Bio % Si   Trout: Rainbow      25.0      21.3     23.3      32.6
MF-TEST .DAT 31 2 Est Bio % Si   Trout: Brook        59.5      52.5     72.2      53.7
MF-TEST .DAT 31 3 Est Bio % Si   Sucker              15.5      26.2      4.5      13.7
```

APPENDIX 4: SAMPLE DATA (MF-TEST.DAT)

```
MICROFISH TEST DATA
1   1   3   161   42.5
1   1   2   118   17
1   1   2   104   16.9
1   1   3   119   27
1   1   3   130   30.9
1   1   2    98   17.2
1   1   2   118   22.2
1   1   3   100   15.1
1   1  10     .     .     11    68.2
1   1  11     .     .      7      .
1   2   3   110   18.2
1   2   3   129   29.2
1   2   2   110   19.4
1   2  10     .     .     11    58.3
1   2  11     .     .      7      .
1   3   3   102   16.5
1   3   3   119   26.5
1   4   3   130   29.8
1   1   3   164   49.5
1   1   2   133   31.2
1   1   3   114   16
1   1   2    96   10.9
1   1   3    68    3.5
1   1   3    77    6
1   1   3    78    3.5
1   1   2    79    4.6
1   1   3    69    4.1
1   1   3    52    1.6
1   1   3    46    1.2
1   1   2    45    1.5
1   1   3    60    3.4
1   1  10     .     .      8    49.6
1   1  11     .     .      3      .
1   2   2    57    2.1
1   3   3    95    9.2
1   4   2   101   10.1
1   4   3    69    3.5
1   1   3   121   19.2
1   1   3   155   36.6
1   1   2   118   18.6
1   1   3    57    3.4
1   1   3   110   15.2
1   1   2    60    4.1
1   1   3    72    6.4
1   1   3    71    5.9
1   1   3    55    4.4
1   1   3    67    2.4
1   1   2    41    2.5
1   1   3    60    1.2
1   1  11     .     .      2      .
1   2   3   139   30.8
1   2   2    62    2.8
1   2   3    38     .5
```

APPENDIX 4: (Con.)

1	2	3	68	3.9		
1	2	2	55	2.3		
1	2	3	47	1.5		
1	2	2	39	.5		
1	2	3	35	.5		
1	3	3	43	.7		
1	3	2	50	.9		
1	3	3	47	.9		
1	3	2	43	.5		
1	3	3	62	1.6		
1	3	2	46	1.3		
1	3	10	.	.	6	42.6
1	3	11	.	.	3	.
1	4	2	63	1.4		
1	4	3	68	2		
1	4	10	.	.	2	11.8
2	1	3	190	94.9		
2	1	3	157	49.4		
2	1	2	101	12.8		
2	1	3	118	18.5		
2	1	3	132	25.4		
2	1	3	109	16.8		
2	1	2	71	5.1		
2	1	3	50	3.1		
2	1	3	61	5		
2	1	3	50	3.2		
2	1	10	.	.	4	19.6
2	1	11	.	.	4	.
2	2	3	56	3.7		
2	2	2	52	2.3		
2	2	3	99	11.5		
2	2	3	59	2.8		
2	2	2	37	.5		
2	2	3	66	3.9		
2	2	10	.	.	2	10.8
2	3	3	51	1.5		
2	3	3	44	1.4		
2	3	3	64	3.5		
2	4	2	60	1.7		
2	4	3	62	2.1		
2	4	10	.	.	1	4.8
2	1	3	109	15		
2	1	2	47	1.1		
2	1	3	55	1.3		
2	2	3	101	11.1		
2	2	3	55	.9		
2	2	2	50	.5		
2	2	3	65	2.2		
2	2	3	71	4.4		
2	3	2	57	.8		
2	3	3	72	2.4		
2	3	3	61	4.0		
2	4	3	99	10.8		
2	1	2	161	42.5		

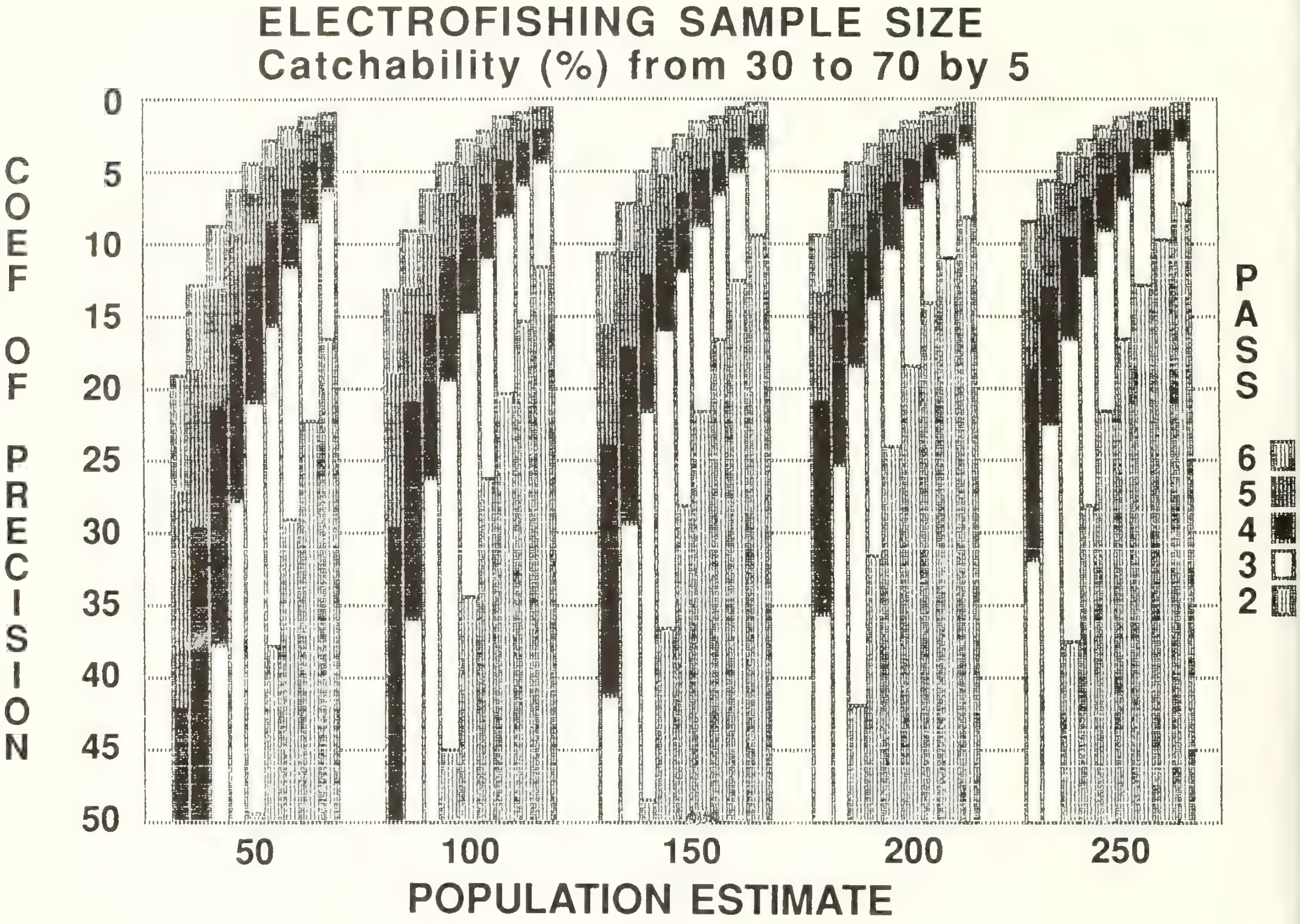
APPENDIX 4: (Con.)

2	1	3	118	17		
2	1	3	104	16.9		
2	1	2	119	27		
2	1	3	130	30.9		
2	1	3	98	17.2		
2	1	3	118	22.2		
2	1	3	100	15.1		
2	2	2	110	18.2		
2	2	3	129	29.2		
2	2	3	110	19.4		
2	3	2	90	10.6		
2	1	2	164	49.5		
2	1	3	133	31.2		
2	1	3	114	16		
2	2	2	96	10.9		
2	2	3	68	3.5		
2	3	3	77	6		
2	4	3	78	3.5		
3	1	3	79	4.6		
3	1	2	69	4.1		
3	1	3	52	1.6		
3	1	3	46	1.2		
3	1	3	45	1.5		
3	1	2	60	3.4		
3	1	10	.	.	6	37.2
3	1	11	.	.	3	.
3	2	2	57	2.1		
3	3	2	95	9.2		
3	4	3	101	10.1		
3	4	3	69	3.5		
3	1	2	121	19.2		
3	1	3	155	36.6		
3	1	3	118	18.6		
3	1	3	57	3.4		
3	1	3	110	15.2		
3	1	2	60	4.1		
3	1	3	72	6.4		
3	1	2	71	5.9		
3	1	3	55	4.4		
3	1	3	67	2.4		
3	1	2	41	2.5		
3	1	3	60	1.2		
3	2	2	139	30.8		
3	2	3	62	2.8		
3	2	3	38	.5		
3	2	3	68	3.9		
3	2	2	55	2.3		
3	2	3	47	1.5		
3	2	3	39	.5		
3	2	3	35	.5		
3	2	10	.	.	3	16.8
3	2	11	.	.	2	.
3	3	2	43	.7		
3	3	3	50	.9		

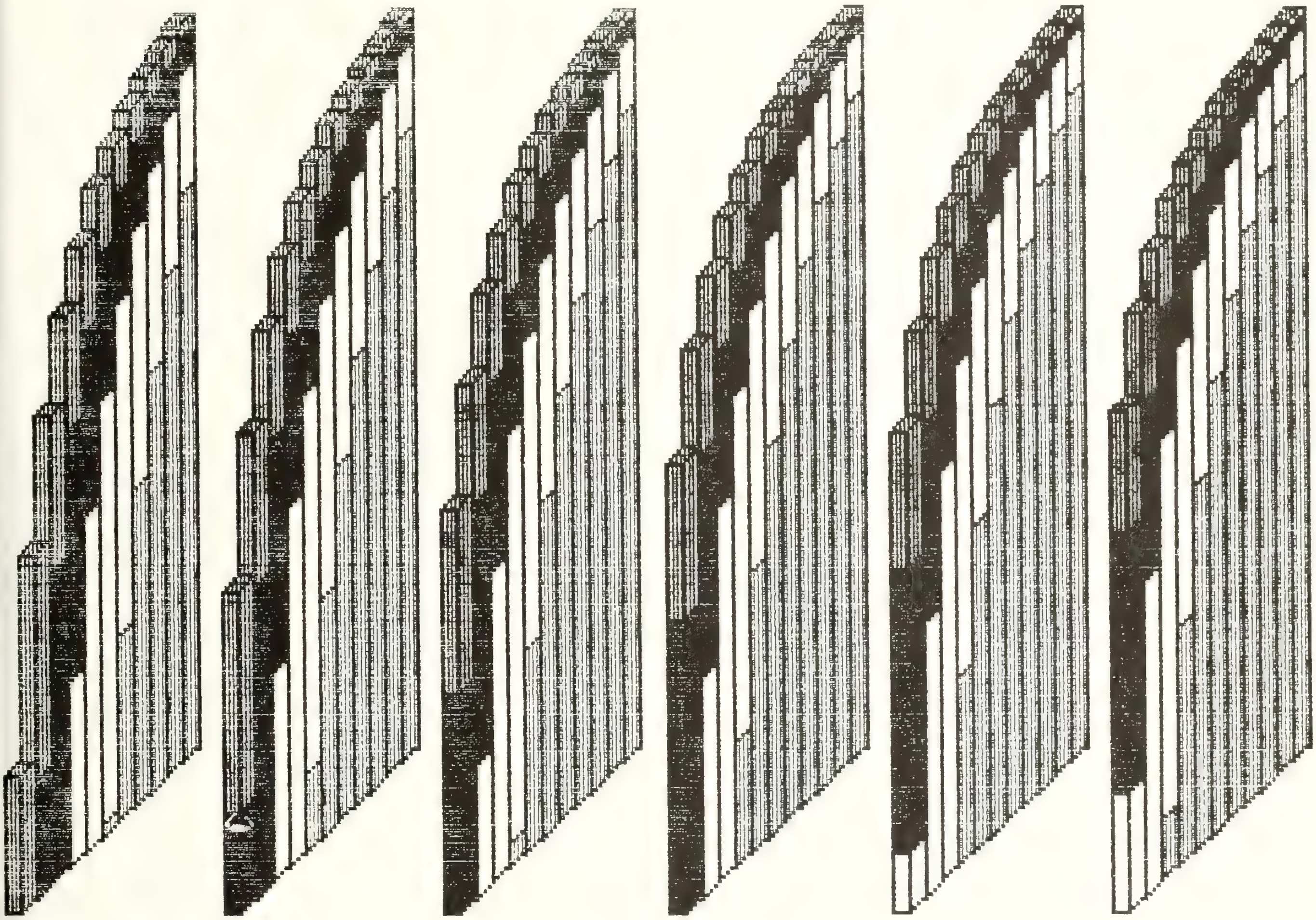
APPENDIX 4: (Con.)

```
3    3    2     47      .9
3    3    2     43      .5
3    3    3     62     1.6
3    3    3     46     1.3
3    3   10      .       .     3    21.0
3    3   11      .       .     5       .
3    4    3     63     1.4
3    4    2     68     2
3    4   10      .       .     1     5.8
3    4   11      .       .     5       .
3    1    3    190    94.9
3    1    2    157    49.4
3    1    3    101    12.8
3    1    3    118    18.5
3    1    3    132    25.4
3    1    2    109    16.8
3    1    3     71     5.1
3    1    2     50     3.1
3    1    2     61     5
3    1    3     50     3.2
3    1    3     56     3.7
3    1    2     52     2.3
3    2    3     99    11.5
3    2    2     59     2.8
3    2    3     37      .5
3    2    3     66     3.9
3    2    2     51     1.5
3    3    2     44     1.4
3    3    3     64     3.5
3    4    2     60     1.7
3    1    2    109    15
3    1    3     47     1.1
3    1    2     55     1.3
3    2    3    101    11.1
3    2    2     55      .9
3    2    3     50      .5
3    2    3     65     2.2
3    2    2     71     4.4
3    4    3     62     2.1
```

APPENDIX 5: OUTPUT EXAMPLE FROM THE MICROFISH SAMPLE SIZE PROGRAM (2-D), (MF-SS2D.EXE)



APPENDIX 6: OUTPUT EXAMPLE FROM THE MICROFISH SAMPLE SIZE PROGRAM (3-D), (MF-SS3D-EXE)



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Van Deventer, John A.; Platts, William S. 1989. Microcomputer software system for generating population statistics from electrofishing data—user's guide for **MicroFish 3.0**. Gen. Tech. Rep. INT-254. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 29 p.

MicroFish (version **3.0**) is a microcomputer software system designed for calculating fisheries population statistics from electrofishing data. System output includes maximum-likelihood population estimates, total catches, capture probabilities, removal patterns, lengths, weights, condition factors, and biomass. Relative percentages, standard errors, and confidence intervals are generated for each sampling site and species in the data set. Output options enable the user to create tables or database files which can be used as input for statistical, spreadsheet, or graphics packages. Sample size programs display two- and three-dimensional color graphs for predicting the number of electrofishing passes needed to achieve a desired precision level in the population estimate.

KEYWORDS: computer, information systems, fisheries management, population estimate, biomass

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Research Station**

General Technical
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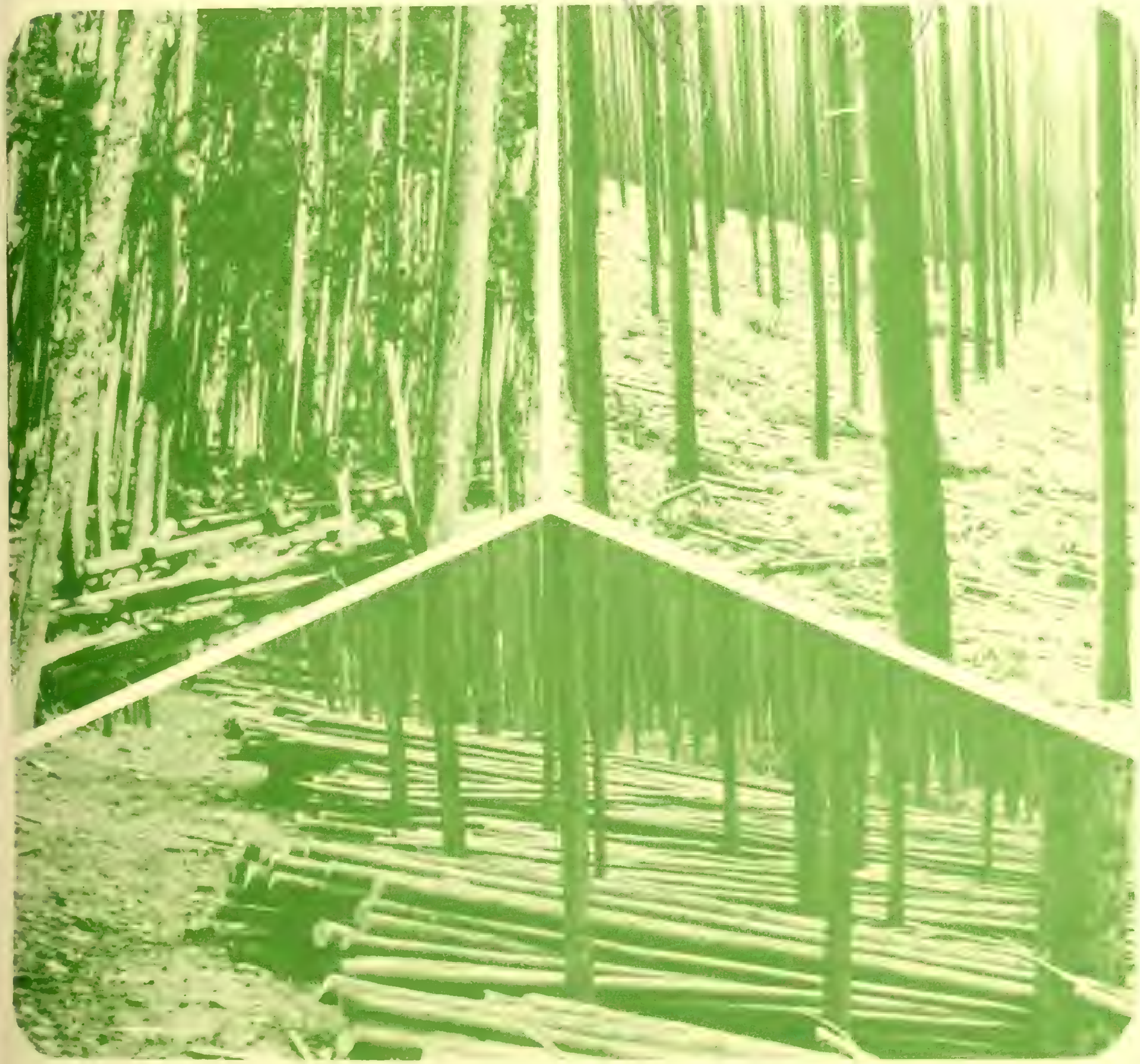
February 1989

Estimating Commercial Product Potential in Small-Stem Lodgepole Pine: Methods, Products, Values

Joyce A. Schlieter
Charles H. Hawkins III



THE AUTHORS

JOYCE A. SCHLIETER was the statistician for the STEM (Systems of Timber Utilization for Environmental Management) Research and Development Program in Missoula, MT, at the time of this study. She is now employed at the Intermountain Research Station's Fire Sciences Laboratory in Missoula.

CHARLES H. HAWKINS III is owner and principal consultant, Rocky Mountain Forestry, White Sulphur Springs, MT. He provides services for private landowners and the forest products industry. This study is one of several he has conducted for the Intermountain Research Station.

ACKNOWLEDGMENTS

This study was conducted under the direction of Roland L. Barger, now retired, who was program manager of STEM (Systems of Timber Utilization for Environmental Management), stationed at the Intermountain Research Station's Forestry Sciences Laboratory, Missoula, MT.

RESEARCH SUMMARY

Managers need a procedure to assess commercial potential in small-stem stands, using conventional stand table or cruise plot information. This report describes a system that predicts merchantable length and potential product recovery using diameter at breast height (d.b.h.) and total height for lodgepole pine trees in 3- through 7-inch d.b.h. classes.

Results of the research include tables of alternative gross product mixes by d.b.h. class, product mix and defect information for nine representative small-stem lodgepole pine stands, and general computer routines. A computer routine enables the user to define a maximum of seven products and obtain product alternatives for each d.b.h. class. If the user has only stand table information available, a second routine evaluates gross product potential based on the user's selected product alternatives. If the user has individual tree records (including defect data), net product potential can be obtained from a third routine.

Users have the option of applying the product information developed for one of the nine representative stands that has characteristics similar to the stand they are evaluating. Users also have the option of selecting their own products to generate alternative product mixes.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

Estimating Commercial Product Potential in Small-Stem Lodgepole Pine: Methods, Products, Values

Joyce A. Schlieter
Charles H. Hawkins III

LODGEPOLE MANAGEMENT NEEDS

Those who manage lodgepole pine stands in the Rocky Mountain West are faced with a major problem: How to achieve multiple-resource management in stands of small-stem, low-value trees. Harvesting merchantable forest products is generally the principal means for meeting objectives not only for timber production but also for other forest resources. Consequently, an important management function is to identify merchandising opportunities, alternatives, and product values. Specific knowledge of the kinds, quantities, and values of merchantable products that can be recovered from a stand will enhance the management planning process.

Product recovery from similar stands in the vicinity may be helpful. But these are not always true indicators of product potential because individual operators are strongly influenced by personal preference, equipment limitations, and market constraints. Forest managers need a method for predicting total product potential in small-stem stands using conventional stand-table or cruise plot information. Also important is the identification of various products or combinations of products and their values recoverable from a stand.

To satisfy this need, we developed a system that enables managers to accurately predict potential of a stand to produce various combinations of common small-diameter roundwood products. Estimates of the gross product potential can be reduced to realistic net estimates based on observed tree defects in the stand. We hope this method will be useful to both land managers and logging contractors in evaluating economic feasibility of specific stands. The ability to identify product potential and maximize value recovery may make the difference between treating and not treating stands that are of questionable profitability.

We had to meet four major objectives to provide maximum flexibility in our product prediction process.

1. Develop a method for estimating gross product potential for a stand from a stand table. This method requires only the availability of a stand table for the timber being examined, and uses average total tree height in each diameter class.
2. Develop a method for estimating gross product potential for a stand from individual tree data, where detailed cruise plot records are available describing individual sample trees.
3. Develop a method for reducing gross product potential to net potential for stands that have individual tree defect data available.
4. Apply gross and net product prediction methods based on individual tree records (items 2 and 3) to nine selected sample stands representing a broad range of tree size and stand density. Describe these stands sufficiently to allow direct comparison with stands of interest to managers, as an alternative to analyzing stand data.

The study approach defined by these objectives was purposely chosen to accommodate a wide range of available stand information. Information available to the manager may vary from detailed individual tree cruise data to aggregate stand table information, or perhaps only a general knowledge of the character of the stand. Objectives 1, 2, and 3 are directed toward providing methods that can effectively use individual tree or stand table information, while objective 4 is concerned with providing actual product information for sample stands which may then be compared to stands of interest.

DEVELOPING THE PREDICTION SYSTEM

Prediction system development made use of stand and tree data accumulated from 19 sample lodgepole pine stands geographically dispersed from the Wasatch-Cache National Forest (Utah-Wyoming) to the Lewis and Clark National Forest (north-central Montana). All stands were essentially pure lodgepole pine, ranging in stand density from 1,000 to 7,000 green stems per acre, and in diameter from 3 to 7 inches d.b.h. They are broadly representative of the extensive overstocked, small-stem lodgepole pine stands occupying several million acres in the Inland West.

Stem Profile Table

The number and kind of roundwood products that can be obtained from a tree are determined by the profile of the stem—butt diameter, rate of taper and upper stem diameters, and length to some minimum usable diameter. As a basis for assessing product potential, we first developed a table of stem profiles that represented the range of tree diameter and height classes encountered on study sites.

An initial question was whether tree d.b.h. and total height alone could explain variation in "merchantable" stem length to various top diameters. We analyzed tree dimension data from the Montana and Utah/Wyoming sites separately, using stepwise regression methods to examine a number of independent variables, including tree d.b.h., total height, stand density, age, and site index. The analyses indicated that d.b.h. and total height were the only variables needed to predict stem length to specified top diameters. Density, age, and site effects are adequately reflected in the diameter-height relationship, and do not have to be accounted for separately. Any one stem d.b.h./height class can therefore be represented by a single stem profile, regardless of stand location or characteristics. Data from the Montana and Utah/Wyoming sites, totaling 341 destructively sampled trees, were consequently pooled to develop regressions predicting stem length to specified top diameters for lodgepole pine trees from 3 to 7 inches d.b.h.

The next step was validation. A second sample of 103 trees was selected from seven of the study stands to cover the range of each d.b.h. class of interest. For example, in the 3-inch class (2.6 to 3.5 inches) in each stand one tree was chosen with d.b.h. between 2.6 and 2.8 inches, one with d.b.h. between 2.9 and 3.2 inches, and one with d.b.h. between 3.3 and 3.5 inches. The selected sample trees were felled, and diameters were recorded at various heights up the stem. Comparisons of measured profiles for these sample trees with predicted profiles from the original stem length regression equations showed a high correlation.

The final step was to combine the original sample (341 trees) with the validation sample (103 trees) and recalculate stem length regression equations. Table 1 shows the resulting predicted stem length to specified top diameters for various d.b.h. and total height combinations. The regressions and tabled values are based on the total sample of 444 felled and measured trees from all 19 sample stands. The stem profiles described by the regressions and table should be representative of all lodgepole pine trees in the diameter and height classes shown.

Product Specifications and Values

Our intent was to develop a procedure that would predict product potential in terms of some common small-diameter products currently utilized by industry operators in the Northern and Central Rocky Mountain area. The product specification search revealed a large number of roundwood products, with length and diameter requirements varying among manufacturers—and virtually no industry standardization. For example, one post and pole yard makes 37 different post products, in addition to a variety of pole and sawed products.

A few products, however, are relatively standardized and represent the range of products and values the average operator might recover. Table 2 lists seven such products, with lengths, minimum and maximum small-end diameters, and values per piece as well as per cubic foot. Values are an amalgamation of prices paid for raw material delivered to manufacturing points early in 1984.

Table 1—Stem profile table for lodgepole pine, indicating length to specified top diameters, by total height and diameter at breast height (d.b.h.) classes

		Diameter at breast height (inches)				
Total height	**Top diameter**[1]	**3**	**4**	**5**	**6**	**7**
Feet	*Inches*			*Feet*		
25	3	4	10			
	2	15	18			
30	4		4	10		
	3	4	13	18		
	2	19	22	24		
35	5			4	11	
	4		4	13	20	
	3	4	17	22	27	
	2	23	26	28	31	
40	5			4	14	22
	4		4	16	23	29
	3	4	21	26	30	35
	2	27	30	33	35	38
45	5			4	16	25
	4		4	19	26	32
	3	4	25	29	34	39
	2	31	34	37	39	42
50	5			4	19	27
	4		4	24	29	36
	3	4	28	33	38	42
	2	36	38	41	43	46
55	5			4	21	30
	4		4	26	32	39
	3		32	37	41	46
	2		42	45	48	50
60	5					32
	4					42
	3					50
	2					54

[1] Regression equations used (for top diameters less than d.b.h.):

Top diameter	Predicted length	R^2	se
2	$-13.685 + 2.64\,(\text{d.b.h.}) + 0.826\,(\text{hgt})$	0.92	2.35
3	$-27.687 + 4.698\,(\text{d.b.h.}) + 0.744\,(\text{hgt})$	.87	3.14
4	$-40.979 + 6.51\,(\text{d.b.h.}) + 0.619\,(\text{hgt})$	.85	3.31
5	$-56.613 + 8.233\,(\text{d.b.h.}) + 0.522\,(\text{hgt})$	.71	3.86

Alternative Gross Product Mixes

Using the stem profile table and the seven specified roundwood products, we developed a system to generate a matrix of all possible gross product alternatives for a tree of specified d.b.h. and height. This may be either the average tree in a d.b.h./height class if a stand table is being used as input data, or the d.b.h. and height class of individual sample trees if individual tree records are

Table 2—Product specifications and values for selected roundwood products commonly recovered from lodgepole pine

Product	Length	Small-end diameter		1984 value[1]	
		Minimum	Maximum	Per piece	Per ft³
	Feet	- - - - - *Inches* - - - - -		- - -*Dollars* - - -	
Post	7	4	7	0.52	0.54
Rail	13	3	5	.65	.49
Rail	17	3	5	1.24	.67
Rail	21	3	5	1.45	.59
Prop	10	2.25	4	.50	.83
Panel pole	17	2	2.5	.50	.86
Barn pole	17	6	7	2.38	.62

[1] Prices paid for raw material f.o.b. manufacturing points.

used. Based on observations of the physical characteristics of small-stem lodgepole pine, certain standard operating rules were established. These constraints included taking 1 foot off the butt end of the tree to avoid butt swell, requiring that props and panel poles come only from the 3- and 4-inch d.b.h. classes (avoiding limby tops), and searching for barn poles only in the 7-inch d.b.h. class. We further specified a minimum "merchantable" top diameter, above which products would not be recovered, for each d.b.h. class:

D.b.h. class	Minimum top diameter
3 and 4	2 inches
5 and 6	3 inches
7	4 inches

To compensate for the fact that trees do not taper uniformly, and also to simplify the computations, an average taper was calculated for each d.b.h. and height. These tapers were derived as averages of whole tree taper to the minimum top diameter and taper in a specified lower segment. The general formula used for taper is given by:

$$\text{taper} = \frac{\text{d.b.h.} - D}{L - 1}$$

For whole tree taper, D is the minimum top diameter given above. For the specified lower segment we used:

D.b.h. class	D
4	3
5	4
6	5
7	5

In both cases, the length L is obtained from table 1 and then 1 foot is subtracted for butt swell. The two tapers coincide for the 3-inch d.b.h. class.

Alternative gross product mixes, residual stem volumes, and tree values for a range of total height classes were developed for the 3- through 7-inch d.b.h. classes (appendix A, tables 3 through 7). Residual volume is the unutilized cubic foot volume to the defined minimum top diameter.

The matrix of alternatives for a particular diameter/height class can be used to pick the product combination that will maximize value. Or, an alternative with desired products can be selected. In this paper, the alternative to maximize value has been used.

Adjusting for Defect

The estimation of gross product potential ignores the possible presence of defect in trees. If limiting or inadmissible defects are present in the stem or stand, actual product recovery will obviously be reduced. As part of this study, we examined alternatives for using individual tree defect data to adjust gross-to-net product potential.

Based on experience with local operators and a survey of manufacturing operations, we defined seven types of defect that influence product recovery. These were crook, fork, fire scar, catface, knot cluster, mistletoe or canker swell, and sweep. Instructions for stem defect sampling are detailed in appendix B. We also developed criteria to assess the effects of defect occurrence on product potential.

Defect analysis was based on individual tree data collected from 1,817 sample trees on nine of the study sites. The exact location of each defect in the stem was recorded, as well as the length of stem affected by the defect. These defective lengths were then deducted from the stem and the remaining stem segments searched for products.

Summaries of the defect occurrence found in each of the nine sample stands are given in appendix C. The percentage of stems with 0, 1, or 2+ defects, as well as the percentage of stems with defects located within each quarter of the merchantable stem length, are reported by d.b.h. class.

Adjustment of potential product recovery to account for defect requires either defect information for individual trees, as was collected for these nine stands, or a "defect factor" based on general experience. To adjust both the product mix recoverable and the value requires individual tree data. A "defect factor" can be applied only as an adjustment to total recovery and value.

APPLICATIONS OF THE METHOD

Managers have three alternatives for predicting product potential, depending on the stand information available. Cruise data for individual sample trees allow direct estimation of gross product potential, tree by tree, as well as reduction to net potential if tree defect information also exists. If information is limited to an aggregate stand table, gross product potential can be estimated using it alone. And if neither sample tree data nor stand table data exist, a manager can simply use the gross and net product potential information developed for a sample stand that most nearly matches the stand of interest.

Gross Product Potential From a Stand Table

To estimate the gross product potential from a stand table, one must know the average total height of trees in each d.b.h. class. This identifies the set of alternative gross product combinations from which one alternative can be chosen for the diameter class. The number of products in the chosen alternative is then multiplied by stems per acre to give predicted gross products per acre for that diameter class. Aggregation of products for all diameter classes indicates total stand product potential per acre.

Appendix C shows stand descriptions that include stand tables for each of the nine sample stands. Gross product estimates are also presented for the product combination that maximizes value in each diameter class.

Gross and Net Product Potential From Individual Tree Data

Individual tree cruise data that include defect information provide the most reliable basis for product prediction. To demonstrate the use of individual tree data, we used the nine sample stands selected to represent typical stand conditions in small-stem lodgepole pine. Six to nine 1/100-acre plots were established in each of these stands. Defect was identified and measured in all trees with at least a 3-inch d.b.h., as previously described. Using individual tree d.b.h. and total height, the value-maximizing product combination from the matrix of alternatives was used to obtain gross product potential, with the assumption that each sample tree was free of defect. To determine net product potential, individual trees were searched for products after all defective portions were eliminated.

The gross and net product estimates resulting from aggregation of individual tree records for each of the nine sample stands are shown in appendix C. These tables also give the unutilized volume to the minimum top diameter, the product value for each d.b.h. class, and total stand value. The reduction in predicted total stand value due to defect ranged from 16 to 46 percent. Product mixes changed and net residual (unused) volume increased. As expected, net values are less than gross values except in a few instances where a specific d.b.h. class had no defect.

Figures 1 to 3 (appendix C) illustrate the gross and net values for the nine sample stands and also show trees per acre. These figures characterize each of the stands in terms of value and defect distribution by d.b.h. class. For example, Ballard Hill South in figure 1 shows that value is concentrated in the 6- and 7-inch d.b.h. classes; Corduroy Creek East in figure 2 shows that the greatest reductions due to defect are in the 3- and 4-inch d.b.h. classes. Some differences may be large, partly because of reductions in the number of products made and partly because of higher valued products being replaced by lower valued products.

Product Potential by Comparing Stands

The nine stands for which gross and net product potential have been calculated, based on individual tree data, represent a wide range of stand conditions. In the absence of specific stand table or cruise data, or as a matter of expediency, a manager can simply use product information for one of these stands that most nearly matches a stand of interest. Important stand comparison criteria are size class distribution of stems, stand density, and defect occurrence. If a stand is similar in these respects to one of the nine stands analyzed, the product potential should also be similar.

Managers may also have stand information—a stand table, for example—that allows estimation of gross product potential, but no information describing defect in the stand. Comparison with one of the nine sample stands provides a way of choosing a "defect factor" or value reduction factor that can be used to adjust gross product potential.

THE COMPUTER ROUTINES

Three computer routines are presented here for use in applying our methodology (appendix D). These programs are written in standard FORTRAN 77 and have been run on the Forest Service Data General system and on a minicomputer in Missoula. A software package is not available, but program documentation is as complete as possible. Minimal programming changes should allow running the routines on a wide variety of computers.

The choice of routines to be used will depend on needs and available information. One program allows the user to specify different products and values in order to obtain product alternatives consistent with particular utilization objectives. When only stand table information is available, a second program will give gross product estimates based on the user's selected product alternatives. If the user has cruise plot records describing individual trees and their defects, the net product estimates can be obtained from a third program.

To Obtain Gross Product Alternatives

This routine gives the user the option to define a maximum of seven products. Length and diameters for the small end and large end, as well as value, must be entered by the user for each product. The user is queried for this information at run time. The program output is a set of tables showing alternatives by tree d.b.h. and total height for the chosen products (similar to the tables displayed in appendix A). Sometimes alternatives are redundant because the program does not check for that. The user needs to look over the listing. Redundancies have been deleted from the tables in appendix A.

The user needs to be aware that the order in which products are entered will affect the output. Also, the user should keep in mind that this program gives an approximation. Expected alternatives sometimes do not appear. In spite of these drawbacks, the program can be a useful tool.

To Obtain Gross Estimates From a Stand Table

This program requires stand table information. In addition, a set of product alternatives must be chosen. These could be based on products selected by us or on products selected by the user. The product alternative data are entered at run time. A worksheet is given following program 2 (appendix D) to assist the user. The output gives an evaluation of product mixes and values by d.b.h. class for the particular stand.

To Obtain Net Estimates

This program requires information describing individual tree pieces after any defective portions have been removed. The user must provide a data file containing this information. Details on the contents of this file are given at the end of program 3 (appendix D). Also, a set of product specifications and values (as shown in table 2) is needed; this information is entered at run time. The output gives product mixes and values for only the trees in the stand containing defects. This output needs to be combined with the products obtained from the trees completely free of defect. For trees free of defect, the chosen product alternative will provide the product mix and value.

MANAGEMENT IMPLICATIONS

Major results of our study include the stem profile table, tables of gross product mixes for our defined group of products, and product prediction results for the nine sample stands. This information can be of value to anyone who is working with comparable products and stands. Of particular importance is the computer routine that generates alternative gross product mixes for user-specified products.

These methods are useful to anyone who needs to identify merchandising opportunities, alternatives, and values. They can be used to enhance land management planning and to facilitate financial decisions. Land managers, appraisers, and forest products firms will find this procedure useful for evaluating stands in terms of currently marketable products. Others, such as entrepreneurs, economists, or consultants, may use this technique to analyze stand potential based on a variety of theoretical product and price combinations. In any case, a user can tailor the process by defining appropriate product specifications, values, and defect criteria.

A practical application of these methods would be an entrepreneur who has developed a use for a high volume of small-stem lodgepole pine of specific dimensions and quality. This raw material is available for purchase on a per-acre basis in conjunction with a prescribed stand treatment. To assess recovery and value per acre, the entrepreneur will want to know the volume of preferred products that can be generated as well as the volume and value of additional products that might be salvaged and sold. This evaluation can be achieved by entering user-defined product specifications and values into the computer program and then searching for a product combination alternative that maximizes the preferred product. Such analysis could be based on intensive field sampling of proposed sale areas or on extensive sampling of representative stand types. Individual tree records and detailed defect data from cruise plots will provide the most reliable results. But a useful analysis might also be made from available stand table information.

APPENDIX A: ALTERNATIVE GROSS PRODUCT MIXES AND VALUES

This appendix displays tables of alternative gross product combinations for the 3- through 7-inch d.b.h. classes of lodgepole pine (tables 3-7). The unutilized cubic foot volume to the defined minimum top diameter for each class is given in the column headed "residual." The values shown are 1984 values (see table 2).

Table 3—Alternative gross product mixes and values for the 3-inch d.b.h.class of lodgepole pine

Total height	Alternative	10-foot prop	Panel pole	Residual volume	Value
				Ft³	
25	1	1	0	0.11	$0.50
30	1	1	0	.23	.50
	2	0	1	.03	.50
35	1	1	0	.36	.50
	2	0	1	.13	.50
40	1	1	0	.49	.50
	2	0	1	.25	.50
45	1	1	1	.09	1.00
50	1	1	1	.23	1.00
	2	0	2	.05	1.00

Table 4—Alternative gross product mixes and values for the 4-inch d.b.h. class of lodgepole pine

Total height	Alternative	13-foot rail	17-foot rail	21-foot rail	10-foot prop	Panel pole	Residual volume	Value
							Ft³	
25	1	0	0	0	1	0	0.27	$0.50
30	1	0	0	0	1	0	.45	.50
35	1	1	0	0	1	0	.05	1.15
	2	0	0	0	2	0	.16	1.00
	3	0	0	0	0	1	.53	.50
40	1	1	0	0	1	0	.18	1.15
	2	0	1	0	1	0	.03	1.74
	3	0	0	0	2	0	.30	1.00
	4	0	0	0	1	1	.03	1.00
45	1	1	0	0	2	0	.00	1.65
	2	1	0	0	0	1	.04	1.15
	3	0	1	0	1	0	.15	1.74
	4	0	0	0	3	0	.05	1.50
	5	0	0	0	1	1	.21	1.00
50	1	1	0	0	2	0	.08	1.65
	2	1	0	0	0	1	.23	1.15
	3	0	1	0	2	0	.00	2.24
	4	0	1	0	0	1	.03	1.74
	5	0	0	1	1	0	.14	1.95
	6	0	0	0	3	0	.19	1.50
	7	0	0	0	2	1	.00	1.50
55	1	1	0	0	2	0	.21	1.65
	2	1	0	0	1	1	.00	1.65
	3	1	0	0	0	1	.46	1.15
	4	0	1	0	2	0	.06	2.24
	5	0	1	0	0	1	.21	1.74
	6	0	0	1	1	0	.28	1.95
	7	0	0	1	0	1	.01	1.95
	8	0	0	0	3	0	.37	1.50
	9	0	0	0	2	1	.06	1.50

Table 5—Alternative gross product mixes and values for the 5-inch d.b.h. class of lodgepole pine

Total height	Alternative	7-foot post	13-foot rail	17-foot rail	21-foot rail	Residual volume	Value
						Ft^3	
30	1	1	0	0	0	0.77	$0.52
	2	0	1	0	0	.26	.65
	3	0	0	1	0	.00	1.24
35	1	1	1	0	0	.06	1.17
	2	0	0	1	0	.23	1.24
	3	0	0	0	1	.00	1.45
40	1	2	0	0	0	.78	1.04
	2	1	1	0	0	.31	1.17
	3	1	0	1	0	.04	1.76
	4	0	0	0	1	.20	1.45
45	1	2	1	0	0	.03	1.69
	2	1	0	1	0	.21	1.76
	3	1	0	0	1	.00	1.97
	4	0	2	0	0	.08	1.30
50	1	2	1	0	0	.24	1.69
	2	2	0	1	0	.00	2.28
	3	1	0	0	1	.15	1.97
	4	0	2	0	0	.30	1.30
	5	0	1	1	0	.03	1.89
55	1	3	1	0	0	.05	2.21
	2	2	0	1	0	.24	2.28
	3	2	0	0	1	.00	2.49
	4	1	2	0	0	.11	1.82
	5	0	1	1	0	.30	1.89
	6	0	1	0	1	.03	2.10
	7	0	0	2	0	.03	2.48

Table 6—Alternative gross product mixes and values for the 6-inch d.b.h. class of lodgepole pine

Total height	Alternative	7-foot post	13-foot rail	17-foot rail	21-foot rail	Residual volume	Value
						Ft^3	
35	1	2	0	0	0	1.08	$1.04
	2	1	1	0	0	.48	1.17
	3	1	0	1	0	.17	1.76
	4	0	2	0	0	.06	1.30
	5	0	0	0	1	.33	1.45
40	1	3	0	0	0	.60	1.56
	2	2	1	0	0	.11	1.69
	3	1	0	1	0	.31	1.76
	4	1	0	0	1	.00	1.97
	5	0	2	0	0	.16	1.30
45	1	3	0	0	0	.97	1.56
	2	2	1	0	0	.40	1.69
	3	2	0	1	0	.08	2.28
	4	1	2	0	0	.00	1.82
	5	1	0	0	1	.28	1.97
	6	0	1	1	0	.14	1.89
50	1	4	0	0	0	.62	2.08
	2	3	1	0	0	.11	2.21
	3	2	0	1	0	.34	2.28
	4	2	0	0	1	.01	2.49
	5	1	2	0	0	.18	1.82
	6	1	1	1	0	.00	2.41
	7	0	1	0	1	.19	2.10
	8	0	0	2	0	.20	2.48
55	1	4	0	0	0	.87	2.08
	2	3	1	0	0	.32	2.21
	3	3	0	1	0	.00	2.80
	4	2	2	0	0	.00	2.34
	5	2	0	0	1	.21	2.49
	6	1	1	1	0	.07	2.41
	7	0	1	0	1	.62	2.10
	8	0	0	2	0	.63	2.48
	9	0	0	1	1	.30	2.69

Table 7—Alternative gross product mixes and values for the 7-inch d.b.h. class of lodgepole pine

Total height	Alternative	7-foot post	13-foot rail	17-foot rail	21-foot rail	Barn pole	Residual volume	Value
							Ft^3	
40	1	4	0	0	0	0	0.10	$2.08
	2	2	1	0	0	0	.18	1.69
	3	1	0	1	0	0	.72	1.76
45	1	4	0	0	0	0	.39	2.08
	2	2	1	0	0	0	.49	1.69
	3	2	0	1	0	0	.05	2.28
	4	2	0	0	0	1	.05	3.42
	5	0	1	0	0	1	.13	3.03
	6	1	0	0	1	0	.73	1.97
50	1	5	0	0	0	0	.15	2.60
	2	3	1	0	0	0	.23	2.21
	3	2	0	1	0	0	.52	2.28
	4	2	0	0	1	0	.09	2.49
	5	2	0	0	0	1	.52	3.42
	6	0	1	0	0	1	.62	3.03
	7	0	0	1	0	1	.18	3.62
55	1	5	0	0	0	0	.43	2.60
	2	3	1	0	0	0	.53	2.21
	3	3	0	1	0	0	.10	2.80
	4	2	0	0	1	0	.38	2.49
	5	3	0	0	0	1	.10	3.94
	6	1	1	0	0	1	.19	3.55
	7	0	0	1	0	1	.48	3.62
	8	0	0	0	1	1	.05	3.83
60	1	5	0	0	0	0	.78	2.60
	2	4	1	0	0	0	.14	2.73
	3	3	0	1	0	0	.42	2.80
	4	2	0	0	1	0	.90	2.49
	5	3	0	0	0	1	.42	3.94
	6	1	1	0	0	1	.52	3.55
	7	1	0	1	0	1	.10	4.14
	8	0	0	0	1	1	.38	3.83
	9	2	2	0	0	0	.47	2.34

APPENDIX B: SAMPLING STEM DEFECT

The following section describes a procedure for sampling stem defect that will yield the data needed to calculate net product potential. This section includes definitions of primary defects and instructions for measuring them. A field form is also offered, along with defect codes and code descriptions.

Defect should be observed and recorded for all trees 3 inches and larger in d.b.h. on plots located in the stand of interest. We used 1/100-acre plots (11.8-foot radius) systematically distributed across the stand, with six to nine plots per stand.

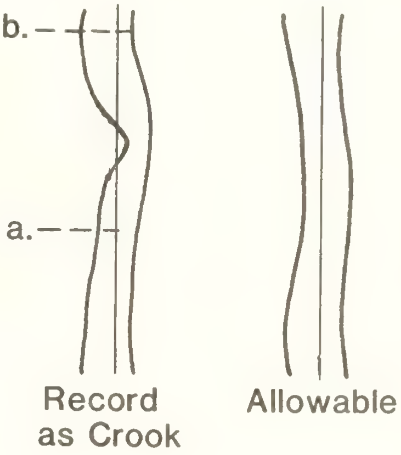
Each defect (trees may have multiple defects) should be observed and measured in the primary stem of each plot tree 3+ inches d.b.h., to a minimum top diameter as follows:

D.b.h. class	Minimum top diameter *Inches*
3-4	2
5-6	3
7+	4

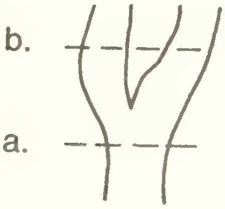
Defects Observed

The defects observed and measured in each sample tree include the following:

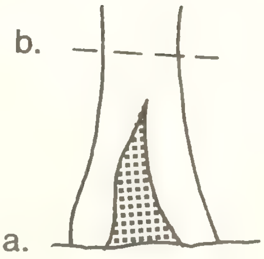
CROOK: A localized stem deviation that is severe enough (equal to or exceeds half the stem diameter) to require bucking out.



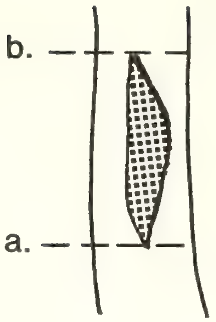
FORK: A more or less equal division of the primary stem.



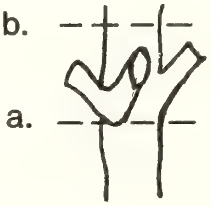
FIRE SCAR: Usually basal, flattened, with char, rot, or exposed wood. Exposed or distorted wood is a defect.



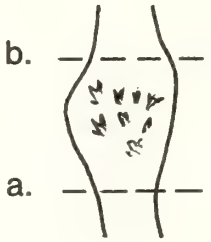
CATFACE: Scar on the bole resulting from fire, earlier nonlethal beetle attacks, falling snags, or other physical damage. Significant exposed wood constitutes a defect.



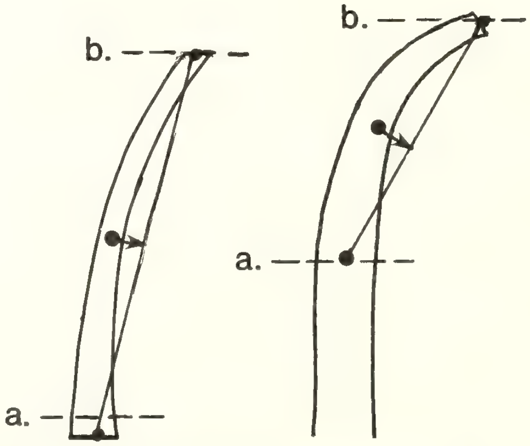
KNOT CLUSTER: A concentration of limbs within a 1-foot stem section, such that the section would require bucking out (generally associated with abnormal growth, witches broom, etc.).



MISTLETOE OR CANKER SWELL: An abnormal swelling with accompanying canker or mistletoe sprouts evident.



SWEEP: A gradual curvature of either the entire merchantable stem, or some major portion of the stem, exceeding allowable limits for roundwood products—generally, centerpoint deviation exceeding the diameter of the stem.



Because trees will not be felled, defects are observed from the ground. A collapsible measuring pole is useful to measure height (to nearest tenth of a foot) to defects in the first 30 feet of the bole. Heights should be measured **from groundline** to points a. and b., representing the portion of the stem that would not be usable for conventional post and pole products.

Point a. and b. measurements for defects within the merchantable stem above 30 feet can be estimated, using the pole as a reference.

Base of the live crown is indicated on the field form and is optional. Defect codes, specific tree data requirements, plot identification, and so forth are also given on the field form.

Lodgepole Pine Defect Field Form

Page ______ of ______

Measured by: ____________________

Stand name: ____________________

Measurement date			Region	Forest	District	Stand	Treatment	Plot
XX	XX	XX	X	X	X	XX	X	XX
Month	Day	Year	Code	Code	Code	Number	Number	Number

Tree number XX	D.b.h. XX.X	Base live crown XX	Total tree height XX	Defect bottom height XX.X	Defect top height XX.X	Defect code X	Observer notes 1/100-acre plots (11.8-foot radius)

NOTE: All heights are measured from ground line. Base of live crown and total tree height are measured to the nearest foot; bottom and top of defects to the nearest half foot.

Minimum merchantable diameters:

2.6-2.8 2.9-3.2 3.3-3.5 = 2-inch top
3.6-3.8 3.9-4.2 4.3-4.5 = 2-inch top
4.6-4.8 4.9-5.2 5.3-5.5 = 3-inch top
5.6-5.8 5.9-6.2 6.3-6.5 = 3-inch top
6.6-6.8 6.9-7.2 7.3-7.5 = 4-inch top

Defect codes: 1 = crook; 2 = fork; 3 = fire scar; 4 = catface; 5 = knot cluster; 6 = swell; 7 = sweep; 8 = other.

Defect Code Definition

CODE NUMBER

1 = CROOK: Localized stem deviation severe enough (equal to or exceeds half the stem diameter) to require bucking out.

2 = FORK: A more-or-less equal division of the central stem.

3 = FIRE SCAR: Usually basal, flattened, with char, rot, or exposed wood. Exposed or distorted wood is a defect.

4 = CATFACE: Scar on the bole resulting from falling snags or other physical damage. Significant exposed wood constitutes a defect.

5 = KNOT CLUSTER: A concentration of limbs within a 1-foot stem section, would require bucking out (generally associated with abnormal growth, witches broom, etc.).

6 = MISTLETOE OR CANKER SWELL: An abnormal swelling, with evident canker or mistletoe sprouts.

7 = SWEEP: A gradual curvature of either the entire merchantable stem, or some major portion of the stem, exceeding allowable limits for roundwood products—generally, centerpoint deviation exceeding the diameter of the stem.

8 = OTHER DEFECT: Details should be explained in notes on field sheets.

APPENDIX C: DESCRIPTIONS AND SUMMARIES FOR NINE SAMPLE STANDS

This appendix provides narrative descriptions and tabular summaries for nine sample stands to which the product prediction methods have been applied. Each stand description includes a tabulated stand inventory followed by three tables: gross product estimates based on the stand table, a summary of defect occurrence, and gross/net product estimates developed from individual sample tree records. Figures 1-3 at the end of the appendix allow a visual comparison of the stands.

Ballard Hill North

STAND DESCRIPTION

Location—This unit is located on the Deerlodge Ranger District of the Deerlodge National Forest, in T. 8 N., R. 11 W., sec. 4, Montana Principal Meridian. The unit is approximately 10 miles south of Gold Creek, MT, via Gold Creek Road (No. 636) and Ballard Hill Road (No. 5168).

Physical Features and Climate—This stand is located on 10- to 30-percent slopes on a northeast-facing aspect at an elevation of 6,300 feet. Local relief is characterized by straight or convex linear slope shape. Mean annual precipitation is 20 inches, as estimated from SCS precipitation maps. Mean annual temperature (30-year normal) for nearby Philipsburg is 41 °F, with July normals of 61 °F and January normals of 21 °F.

Vegetation—This is an 80-year-old lodgepole pine stand having a site index of 94. Habitat type for this stand is *Abies lasiocarpa/Linnaea borealis-Linnaea borealis* phase. The dominant seral species is *Pinus contorta*. The understory is dominated by *Vaccinium globulare, V. scoparium, Arnica latifolia, A. cordifolia,* and *Chimaphila umbellata. Goodyera oblongifolia, Linnaea borealis,* and *Xerophyllum tenax* are common. *Spiraea betulifolia, Lonicera utahensis*, and *Arctostaphylos uva-ursi* are present infrequently. Pinegrass is expected but not found in our samples.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on seven 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft^3*
3	39.8	1,000	1,070
4	47.0	786	1,737
5	52.5	400	1,520
6	57.0	157	920
7	60.9	57	479

SUMMARIES (TABLES 8-10)

Table 8—Gross product estimates per acre for the Ballard Hill North sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	*- - - - - - - - - - - Number*						*- - - - - - - - - - -*	*Ft^3*	
3						1,000		250.00	$ 500.00
4			786		786			117.90	1,367.64
5	800			400				0.00	996.00
6	471		157					0.00	439.60
7	57		57				57	5.70	235.98
Total									$3,539.22

[1]Products: 1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 9—Summary of defect occurrence for the Ballard Hill North sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				
	0	1	2+	1	2	3	4	Sweep
Inches	*Percentage of stems*							
3	47	42	11	35	7	7	13	1
4	47	38	15	27	9	18	11	4
5	54	39	7	29	7	14	4	0
6	73	27	0	18	9	0	0	0
7	75	25	0	25	0	0	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.

[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 10—Gross and net product estimates per acre for the Ballard Hill North sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft*^{3}	
3	Gross					186	871		113.54	$528.50
	Net					200	671		220.01	435.50
4	Gross		200	486		915			83.59	1,190.14
	Net		157	257		815	100		234.14	878.23
5	Gross	643		200	200				0.56	872.36
	Net	614	14	243	100				125.85	774.70
6	Gross	400		114	43				1.41	411.71
	Net	371		71	86				18.78	405.66
7	Gross	100		29				57	5.00	223.62
	Net	100		28				57	11.07	222.38
Total										
	Gross									$3,226.33
	Net									$2,716.47

Reduction in total value due to defect = 15.8 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Ballard Hill South

STAND DESCRIPTION

Location—This unit is located on the Deerlodge Ranger District of the Deerlodge National Forest, in T. 8 N., R. 11 W., sec. 4, Montana Principal Meridian. The unit is approximately 10 miles south of Gold Creek, MT, via Gold Creek Road (No. 636) and Ballard Hill Road (No. 5168).

Physical Features and Climate—This stand is located on 10- to 30-percent slopes on a northeast-facing aspect at an elevation of 6,300 feet. Local relief is characterized by straight or convex linear slope shape. Mean annual precipitation is 20 inches, as estimated from SCS precipitation maps. Mean annual temperature (30-year normal) for nearby Philipsburg is 41 °F, with July normals of 61 °F and January normals of 21 °F.

Vegetation—This is an 80-year-old lodgepole pine stand having a site index of 87. Habitat type for this stand is *Abies lasiocarpa/Linnaea borealis-Linnaea borealis* phase. The dominant seral species is *Pinus contorta*. The understory is dominated by *Vaccinium globulare, V. scoparium, Arnica latifolia, A. cordifolia,* and *Chimaphila umbellata. Goodyera oblongifolia, Linnaea borealis,* and *Xerophyllum tenax* are common. *Spiraea betulifolia, Lonicera utahensis*, and *Arctostaphylos uva-ursi* are present infrequently. Pinegrass is expected but not found in our samples.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on seven 1/100-acre plots:

D.b.h. class *Inches*	Average height *Feet*	Stems per acre *Number*	Volume per acre *Ft^3*
3	38.6	243	253
4	46.7	200	438
5	52.9	200	766
6	58.0	314	1,875
7	62.3	214	1,847

SUMMARIES (TABLES 11-13)

Table 11—Gross product estimates per acre for the Ballard Hill South sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1]							Residual volume	Value
	1	2	3	4	5	6	7		
Inches	*Number*							*Ft^3*	
3						243		60.75	$121.50
4			200		200			30.00	348.00
5	400			200				0.00	498.00
6	942		314					0.00	879.20
7	214		214				214	21.40	885.96
Total									$2,732.66

[1]Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 12—Summary of defect occurrence for the Ballard Hill South sample stand

D.b.h.	Number of defects			Presence of locatable[1] defects by quarter[2]				
class	0	1	2+	1	2	3	4	Sweep
Inches	*Percentage of stems*							
3	24	35	41	53	35	6	24	0
4	7	50	43	86	14	14	14	14
5	0	43	57	50	57	43	21	0
6	23	50	27	50	18	23	9	0
7	46	47	7	40	13	0	7	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.
[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 13—Gross and net product estimates per acre for the Ballard Hill South sample unit, using individual tree records as a basis for prediction

D.b.h.		Products[1]							Residual	
class		1	2	3	4	5	6	7	volume	Value
Inches		*Number*							*Ft*^{3}	
3	Gross					100	143		19.87	$121.50
	Net					43	57		89.56	50.00
4	Gross		86	86		215			25.51	270.04
	Net		14	14		114	71		124.77	118.96
5	Gross	314		57	143				0.56	441.31
	Net	129	43	57	14				337.77	186.01
6	Gross	814		257	57				4.99	824.61
	Net	614	29	157	100				310.17	677.81
7	Gross	271		129				200	26.23	776.88
	Net	415		114				129	121.05	664.18
Total										
	Gross									$2,434.34
	Net									$1,696.96

Reduction in total value due to defect = 30.3 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Dry Fork East

STAND DESCRIPTION

Location—This unit is located on the Kings Hill Ranger District of the Lewis and Clark National Forest, in T. 15 N., R. 8 E., sec. 6, Montana Principal Meridian. It is approximately 14 miles east of Monarch, MT, via Dry Fork Belt Creek Road (No. 120).

Physical Features and Climate—This stand is located on 15- to 30-percent slopes on a north-facing aspect at an elevation of 5,400 feet. Local relief is characterized by straight slopes and benches between deep draws. Mean annual precipitation is 20 inches, based on SCS maps. Annual precipitation for Neihart is 20 to 25 inches.

Vegetation—Dry Fork East is a 57-year-old lodgepole pine stand having a site index of 77. Habitat type for this stand is *Pseudotsuga menziesii/Linnaea borealis-Calamagrostis rubescens* phase. The dominant seral species is *Pinus contorta*. The understory is dominated by *Calamagrostis rubescens, Aster conspicuus, Spiraea betulifolia*, and *Rosa acicularis*. *Symphoricarpos albus, Berberis repens*, and *Linnaea borealis* are common. *Galium boreale, Pyrola secunda*, and *Clematis columbiana* occur. The tall shrub *Acer glabrum* is present.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on nine 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft^3*
3	31.7	666	566
4	36.3	378	635
5	39.8	100	284
6	42.7	11	48
7	45.1	0	0

SUMMARIES (TABLES 14-16)

Table 14—Gross product estimates per acre for the Dry Fork East sample unit, using the stand table as a basis for prediction

D.b.h. class	**Products[1]** 1	2	3	4	5	6	7	**Residual volume**	**Value**
Inches	Number							Ft^3	
3						666		19.98	$333.00
4		378			378			18.90	434.70
5	100		100					4.00	176.00
6	22		11					0.88	25.08
7								0.00	0.00
Total									$968.78

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 15—Summary of defect occurrence for the Dry Fork East sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	25	48	27	27	23	25	23	5
4	21	59	20	21	24	29	32	0
5	56	22	22	0	11	11	33	0
6	0	100	0	100	0	0	0	0
7	0	0	0	0	0	0	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.

[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 16—Gross and net product estimates per acre for the Dry Fork East sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft^3*	
3	Gross					322	344		49.04	$333.00
	Net					211	122		197.95	166.50
4	Gross		167	33		377			81.07	337.97
	Net		44			245	67		191.43	184.60
5	Gross	56		45	55				1.36	164.67
	Net	33		44	44				29.39	135.52
6	Gross	11		11					1.87	19.36
	Net				11				3.22	15.95
7	Gross								0	0
	Net								0	0
Total										
	Gross									$855.00
	Net									$502.57

Reduction in total value due to defect = 41.2 percent

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[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Corduroy Creek East

STAND DESCRIPTION

Location—This unit is located on the Philipsburg Ranger District of the Deerlodge National Forest, in T. 9 N., R. 15 W., sec. 28, Montana Principal Meridian. The unit is approximately 26 miles northwest of Philipsburg, MT, via State Route 348 and Upper Willow Creek Road (No. 88).

Physical Features and Climate—This stand is located on gentle slopes (5 to 10 percent) with a southwest-facing aspect at an elevation of 5,900 feet. Local relief is characterized by convex slopes and benches. Mean annual precipitation is about 20 inches, based on SCS maps. Mean annual temperature of 40 °F at Philipsburg is probably representative. Local frost pockets are commonly encountered.

Vegetation—Corduroy Creek East is an 85-year-old lodgepole pine stand with a site index of 78. Habitat type for this stand is *Abies lasiocarpa/Vaccinium caespitosum*. *Pinus contorta* is the dominant seral species and is often found reproducing. The understory is dominated by *Vaccinium caespitosum, V. scoparium, Calamagrostis rubescens, Linnaea borealis*, and *Arctostaphylos uva-ursi* forming a dense ground cover. *Vaccinium globulare, Spiraea betulifolia*, and *Xerophyllum tenax* are present infrequently.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on six 1/100-acre plots:

D.b.h. class	Average height	Stems per acre	Volume per acre
Inches	*Feet*	*Number*	*Ft³*
3	40.1	700	756
4	46.1	617	1,339
5	50.7	317	1,160
6	54.5	233	1,300
7	57.7	33	262

SUMMARIES (TABLES 17-19)

Table 17—Gross product estimates per acre for the Corduroy Creek East sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1]							Residual volume	Value
	1	2	3	4	5	6	7		
Inches				*Number*				*Ft³*	
3						700		175.00	$350.00
4			617		617			92.55	1,073.58
5	634		317					0.00	722.76
6	699		233					0.00	652.40
7	33		33				33	3.30	136.62
Total									$2,935.36

[1]Products: 1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 18—Summary of defect occurrence for the Corduroy Creek East sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	18	27	55	60	29	20	29	0
4	24	27	49	43	22	22	41	0
5	32	42	26	53	21	11	16	0
6	14	57	29	36	43	7	21	0
7	100	0	0	0	0	0	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.
[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 19—Gross and net product estimates per acre for the Corduroy Creek East sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft³*	
3	Gross					217	567		84.68	$392.00
	Net					167	250		285.79	208.50
4	Gross		67	517		718			55.16	1,043.63
	Net		100	184		518	83		333.85	593.66
5	Gross	617		200	117				0.68	738.49
	Net	433		234	66				178.29	611.02
6	Gross	650		200	33				1.69	633.85
	Net	500		183	50				221.17	559.42
7	Gross	67		17				33	3.30	134.46
	Net	67		17				33	3.30	134.46
Total										
	Gross									$2,942.43
	Net									$2,107.06

Reduction in total value due to defect = 28.4 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Corduroy Creek West

STAND DESCRIPTION

Location—This unit is located on the Philipsburg Ranger District of the Deerlodge National Forest, in T. 9 N., R. 15 W., sec. 28, Montana Principal Meridian. The unit is approximately 26 miles northwest of Philipsburg, MT, via State Route 348 and Upper Willow Creek Road (No. 88).

Physical Features and Climate—This stand is located on gentle slopes (5 to 10 percent) with a southwest-facing aspect at an elevation of 5,900 feet. Local relief is characterized by convex slopes and benches. Mean annual precipitation is about 20 inches, based on SCS maps. Mean annual temperature of 40 °F at Philipsburg is probably representative. Local frost pockets are commonly encountered.

Vegetation—Corduroy Creek West is an 88-year-old lodgepole pine stand with a site index of 69. Habitat type for this stand is *Abies lasiocarpa/Vaccinium caespitosum. Pinus contorta* is the dominant seral species and is often found reproducing. The understory is dominated by *Vaccinium caespitosum, V. scoparium, Calamagrostis rubescens, Linnaea borealis*, and *Arctostaphylos uva-ursi* forming a dense ground cover. *Vaccinium globulare, Spiraea betulifolia*, and *Xerophyllum tenax* are present infrequently.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on six 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft³*
3	37.2	916	916
4	42.7	533	1,066
5	47.0	200	676
6	50.5	150	773
7	53.4	17	125

SUMMARIES (TABLES 20-22)

Table 20—Gross product estimates per acre for the Corduroy Creek West sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	*Number*							*Ft³*	
3						916		119.08	$458.00
4			533		533			79.95	927.42
5	200			200				0.00	394.00
6	300			150				1.50	373.50
7	51						17	1.70	66.98
Total									$2,219.90

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 21—Summary of defect occurrence for the Corduroy Creek West sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	7	39	54	63	31	31	32	0
4	25	28	47	53	28	16	16	0
5	50	17	33	42	8	8	17	0
6	33	33	34	56	33	11	0	0
7	100	0	0	0	0	0	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.
[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 22—Gross and net product estimates per acre for the Corduroy Creek West sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft³*	
3	Gross					300	717		127.78	$508.50
	Net					267	233		395.59	250.00
4	Gross		50	450		599			62.89	890.00
	Net		50	150		383	217		264.83	518.50
5	Gross	350		83	117				0.00	454.57
	Net	267		66	117				89.83	390.33
6	Gross	317		50	100				3.64	371.84
	Net	267	17	17	117				76.17	340.62
7	Gross	17		17				17	1.70	70.38
	Net	17		17				17	1.70	70.38
Total										
	Gross									$2,295.29
	Net									$1,569.83

Reduction in total value due to defect = 31.6 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Echo Lake

STAND DESCRIPTIONS

Location—This unit is on the Philipsburg Ranger District of the Deerlodge National Forest, in T. 6 N., R. 13 W., sec. 31, Montana Principal Meridian. The unit is approximately 2 miles north of Georgetown Lake via Echo Lake Road.

Physical Features and Climate—This stand is located on a 20 percent slope with northwest-facing aspect at an elevation of 6,700 feet. Local relief is characterized by straight linear slopes. Mean annual precipitation is 18 inches, represented by the 30-year normal from nearby Silver Lake. Mean annual temperature is likely slightly lower than the 40 °F for Philipsburg.

Vegetation—This is an 88-year-old lodgepole pine stand having a site index of 70. Habitat type for this stand is *Pseudotsuga menziesii/Linnaea borealis-Calamagrostis rubescens* phase. The dominant seral species is *Pinus contorta*. The understory is dominated by *Arnica latifolia, Calamagrostis rubescens, Vaccinium myrtillus*, and *Linnaea borealis*. *Vaccinium globulare, Spiraea betulifolia, Menziesia ferruginea*, and *Alnus sinuata* are present infrequently.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on six 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft^3*
3	36.3	1,667	1,634
4	41.5	600	1,164
5	45.6	100	327
6	48.8	83	413
7	51.6	0	0

SUMMARIES (TABLES 23-25)

Table 23—Gross product estimates per acre for the Echo Lake sample unit, using the stand table as a basis for prediction

D.b.h.	Products[1]							Residual	
class	1	2	3	4	5	6	7	volume	Value
Inches	*Number*							*Ft^3*	
3						1,667		216.71	$833.50
4			600		600			18.00	1,044.00
5	100			100				0.00	197.00
6	166			83				0.83	206.67
7								0.00	0.00
Total									$2,281.17

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 24—Summary of defect occurrence for the Echo Lake sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	46	42	12	38	9	5	8	0
4	56	28	16	25	8	17	11	0
5	83	0	17	17	0	0	17	0
6	80	0	20	20	20	0	0	0
7	0	0	0	0	0	0	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.

[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 25—Gross and net product estimates per acre for the Echo Lake sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft³*	
3	Gross					350	1,350		168.31	$850.00
	Net					300	1,084		337.32	692.00
4	Gross		167	417		618			37.96	934.63
	Net		83	250		616	100		138.49	721.95
5	Gross	133		33	67				0.00	207.23
	Net	117		34	67				10.17	200.15
6	Gross	233		83					1.36	224.08
	Net	200		84					42.53	208.16
7	Gross								0	0
	Net								0	0
Total										
	Gross									$2,215.94
	Net									$1,822.26

Reduction in total value due to defect = 17.8 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Getcho

STAND DESCRIPTION

Location—This unit is located on the Hebgen Lake Ranger District of the Gallatin National Forest, in T. 14 S., R. 5 E., sec. 9, Montana Principal Meridian. The unit is approximately 3 miles southwest of West Yellowstone, MT, via a spur road off Madison Plateau Road 1700.

Physical Features and Climate—This stand is located on gentle (0 to 10 percent) slopes with a southwest-facing aspect at an elevation of 6,800 feet. Local relief is characterized by gently rolling terrain. Mean annual precipitation is 25 to 30 inches. Long-term (30-year normal) mean for West Yellowstone is 22 inches, with 60 percent of this coming as snow. Normal mean annual temperature for West Yellowstone is 35 °F, with July normals of 60 °F and January normals of 12 °F. Frost-free season is short (50 to 90 days).

Vegetation—This is a 100-year-old lodgepole pine stand having a site index of 62. Habitat type for this stand is *Abies lasiocarpa / Calamagrostis rubescens*. The dominant seral species is *Pinus contorta*. The understory is dominated by *Calamagrostis rubescens* and *Vaccinium scoparium*. *Arnica latifolia*, *Lupinus* sp., and *Vicia americana* occur frequently. No tall shrubs were found.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on eight 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft³*
3	35.3	375	356
4	41.0	463	884
5	45.4	313	1,020
6	49.0	150	749
7	52.0	50	357

SUMMARIES (TABLES 26-28)

Table 26—Gross product estimates per acre for the Getcho sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	*Number*							*Ft³*	
3						375		48.75	$187.50
4			463		463			13.89	805.62
5	313			313				0.00	616.61
6	300			150				1.50	373.50
7			50				50	9.00	181.00
Total									$2,164.23

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 27—Summary of defect occurrence for the Getcho sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	3	38	59	84	19	22	25	6
4	3	24	73	92	24	35	24	5
5	4	28	68	80	24	40	12	4
6	0	33	67	83	33	8	25	0
7	0	0	100	100	50	75	0	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.

[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 28—Gross and net product estimates per acre for the Getcho sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft³*	
3	Gross					100	275		34.75	$187.50
	Net					88	101		139.56	94.50
4	Gross		125	263		463			46.39	638.87
	Net		25	13		351	50		337.91	232.87
5	Gross	375		112	200				1.48	623.88
	Net	200	63	101	75				287.95	378.94
6	Gross	313		87	63				4.38	361.99
	Net	238		113	25				131.50	300.13
7	Gross	75		25				50	5.31	189.00
	Net	88	13	13					148.63	70.33
Total										
	Gross									$2,001.24
	Net									$1,076.77

Reduction in total value due to defect = 46.2 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Cottonwood Ridge East

STAND DESCRIPTION

Location—This unit is located on the Mountain View Ranger District of the Wasatch National Forest in T. 3 N., R. 14 E., sec. 21, Salt Lake Principal Meridian. The unit is approximately 26 miles south of Mountain View, WY, via Bridger Lake Road (No. 072), Road No. 017, and Road No. 087.

Physical Features and Climate—This stand is located on 3- to 5-percent slopes with northeast- to east-facing aspects at an elevation of 9,600 feet. Local relief is characterized by gently sloping benches dissected with very shallow and flat drainages. Mean annual precipitation is 26 inches. Mean annual temperature is 28 °F, with a July mean of 50 °F and a January mean of 13 °F.

Vegetation—This is a 120-year-old lodgepole pine stand with a site index of 52. Habitat type for this stand is *Pinus contorta/Vaccinium scoparium. Pinus contorta* is the dominant seral species and is often found reproducing. The understory is dominated by *Vaccinium scoparium. Arnica cordifolia, Poa nervosa, Antennaria* spp., *Fragaria virginiana, Arnica rossii,* and *Aster* spp. are commonly encountered. *Epilobium angustifolium, Achillea millefolium,* and *Hieracium albiflorum* are also present. Litter covers 76 to 86 percent of the ground.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on seven 1/100-acre plots:

D.b.h. class	**Average height**	**Stems per acre**	**Volume per acre**
Inches	*Feet*	*Number*	*Ft³*
3	27.7	871	636
4	32.3	771	1,149
5	35.8	300	762
6	38.7	29	113
7	41.1	14	78

SUMMARIES (TABLES 29-31)

Table 29—Gross product estimates per acre for the Cottonwood Ridge East sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches				*Number*				*Ft³*	
3						871		26.13	$435.50
4					771			346.95	385.50
5				300				0.00	435.00
6	29			29				0.00	57.13
7	56							1.40	29.12
Total									$1,342.25

[1]Products: 1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 30—Summary of defect occurrence for the Cottonwood Ridge East sample stand

D.b.h. class	Number of defects			Presence of locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	*Percentage of stems*							
3	20	31	49	47	23	24	44	5
4	18	42	40	47	22	35	42	0
5	29	33	38	38	19	29	19	5
6	33	34	33	0	33	0	33	0
7	0	0	100	100	0	0	100	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.
[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 31—Gross and net product estimates per acre for the Cottonwood Ridge East sample unit, using individual tree records as a basis for prediction

D.b.h. class		Products[1]							Residual volume	Value
		1	2	3	4	5	6	7		
Inches		*Number*							*Ft³*	
3	Gross					471	400		68.11	$435.50
	Net					186	157		295.99	171.50
4	Gross		214	14		771			221.99	541.96
	Net		57			486	71		419.35	315.55
5	Gross	114		100	200				2.84	473.28
	Net	100	57	43	100				204.96	287.37
6	Gross	29		14	14				2.38	52.74
	Net	28		28					10.14	49.28
7	Gross	57							1.43	29.64
	Net	43							19.29	22.36
Total										
	Gross									$1,533.12
	Net									$846.06

Reduction in total value due to defect = 44.8 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Cottonwood Mountain

STAND DESCRIPTION

Location—This unit is located on the Mountain View Ranger District of the Wasatch National Forest, in T. 12 N., R. 115 W., sec. 22, sixth principal meridian. The unit is approximately 20 miles south of Mountain View, WY, via Bridger Lake Road (No. 072) and Road No. 017.

Physical Features and Climate—This stand is located on flat ground with northwest- to east-facing aspects at an elevation of 9,400 feet. Local relief is characterized by gently sloping benches dissected with very shallow and flat drainages. Mean annual precipitation is 24.5 inches. Mean annual temperature is 28 °F, with a July mean of 50 °F and a January mean of 13 °F.

Vegetation—Cottonwood Mountain is a 122-year-old lodgepole pine stand, with a site index of 55. Habitat type is *Pinus contorta/Carex rossii*. *Pinus contorta* is the sole tree species. No shrubs were found although *Juniperus communis* or *Rosa* spp. are known to occur. Herbaceous growth is dominated by *Arnica cordifolia, Poa nervosa, Aster* spp., and *Achillea millefolium. Epilobium angustifolium, Penstemon confertus, Calamagrostis rubescens,* and *Trifolium repens* are also present. Litter covers 83 percent of the surface.

Stand Inventory—Based on all stems of 3-inch d.b.h. and larger on six 1/100-acre plots:

D.b.h. class	Average height	Stems per acre	Volume per acre
Inches	*Feet*	*Number*	*Ft^3*
3	28.6	383	291
4	33.9	400	628
5	38.1	417	1,130
6	41.4	200	838
7	44.3	84	507

SUMMARIES (TABLES 32-34)

Table 32—Gross product estimates per acre for the Cottonwood Mountain sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	- - - - - - - - - *Number* - - - - - - - - -							*Ft^3*	
3						383		11.49	$191.50
4		400			400			20.00	460.00
5	417		417					16.68	733.92
6	200			200				0.00	394.00
7	168						84	4.20	287.28
Total									$2,066.70

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

Table 33—Summary of defect occurrence for the Cottonwood Mountain sample stand

D.b.h.	**Number of defects**			**Presence of locatable[1] defects by quarter[2]**				
class	**0**	**1**	**2+**	**1**	**2**	**3**	**4**	**Sweep**
Inches	*Percentage of stems*							
3	11	39	50	39	32	32	50	11
4	15	39	46	54	19	31	42	0
5	46	35	19	15	4	15	31	4
6	23	23	54	23	54	54	23	0
7	29	14	57	29	29	29	43	0

[1] Locatable defects recorded included crook, fork, fire scar, catface, knot cluster, and swell.

[2] Quarter segments are defined as quarters of merchantable stem length (1 = 0 to 25 percent).

Table 34—Gross and net product estimates per acre for the Cottonwood Mountain sample unit, using individual tree records as a basis for prediction

D.b.h.		**Products[1]**							**Residual**	
class		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**volume**	**Value**
Inches		*Number*							Ft^3	
3	Gross					167	217		28.15	$192.00
	Net					116	17		154.06	66.50
4	Gross		117	33		400			107.28	316.97
	Net		67			250	50		185.96	193.55
5	Gross	67		233	183				2.68	589.11
	Net	84	50	150	117				152.06	431.83
6	Gross	233		183	17				28.14	372.73
	Net	150	67	50					259.79	183.55
7	Gross	233		17				33	8.91	220.78
	Net	200		17					125.00	125.08
Total										
	Gross									$1,691.59
	Net									$1,000.51

Reduction in total value due to defect = 40.9 percent

[1] Products:
1 = 7-foot post
2 = 13-foot rail
3 = 17-foot rail
4 = 21-foot rail
5 = 10-foot prop
6 = 17-foot panel pole
7 = 17-foot barn pole

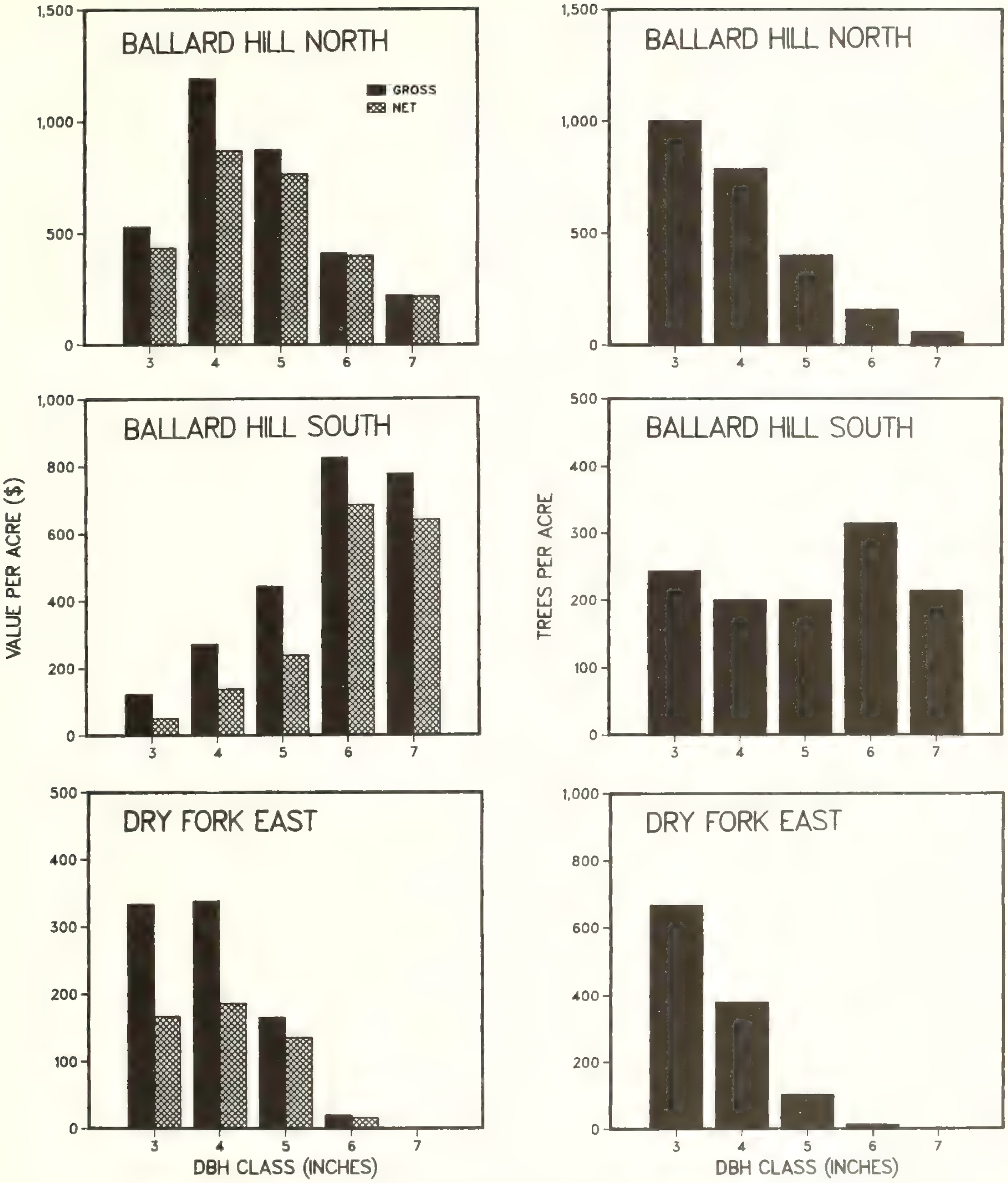

Figure 1—Trees per acre, gross and net values estimated from individual tree data for three of the nine sample stands: Ballard Hill North, Ballard Hill South, and Dry Fork East.

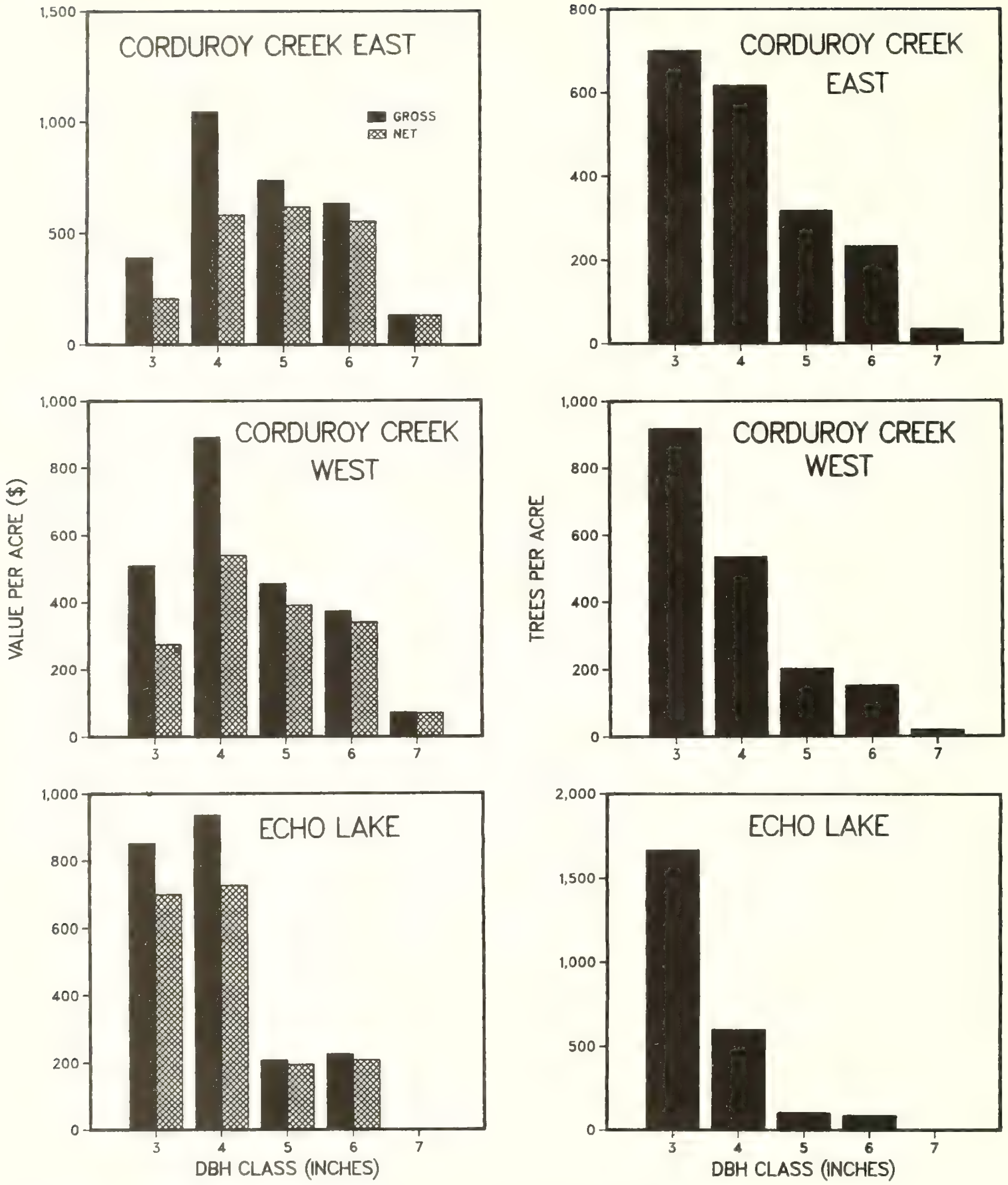

Figure 2—Trees per acre, gross and net values estimated from individual tree data for three of the nine sample stands: Corduroy Creek East, Corduroy Creek West, and Echo Lake.

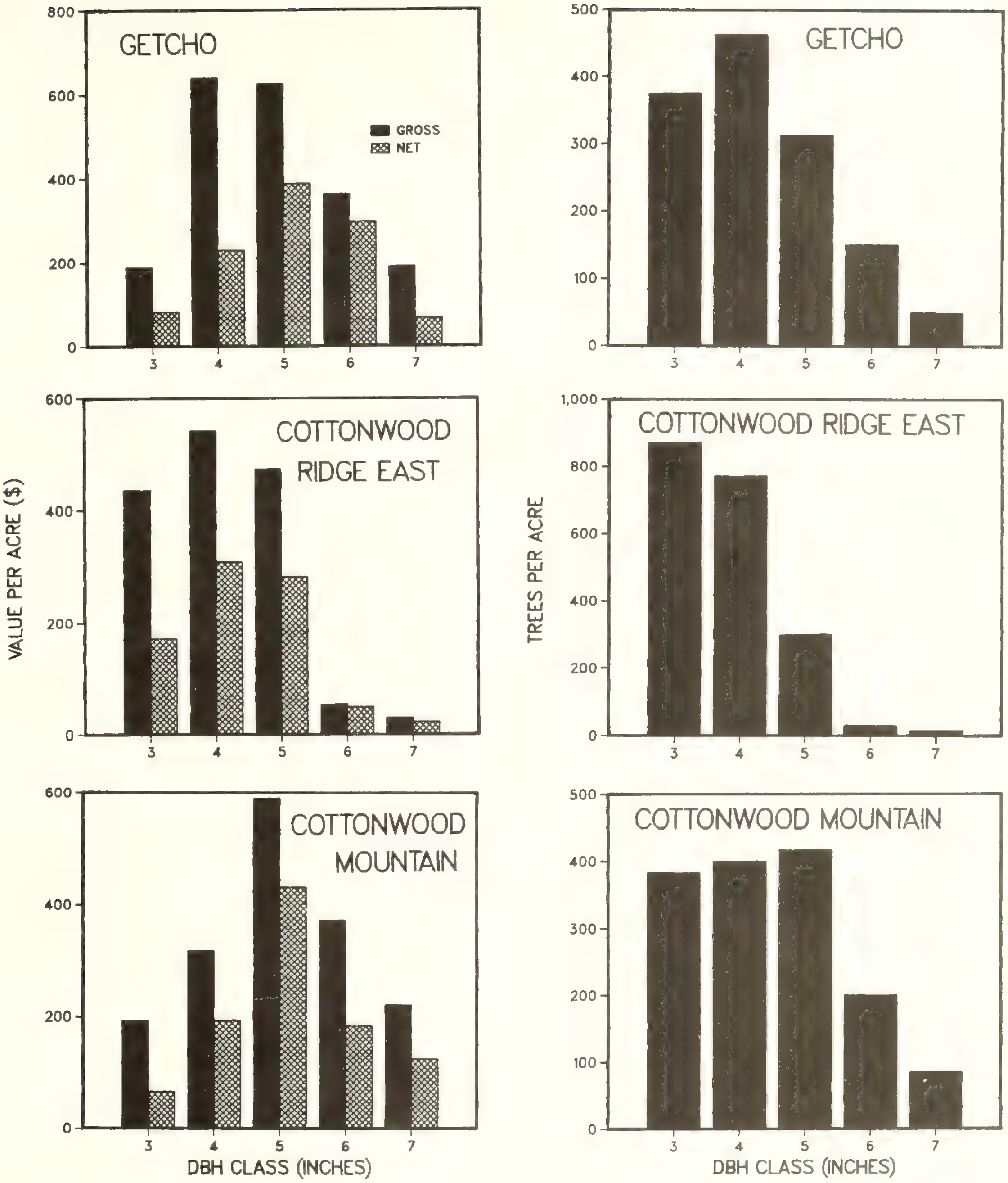

Figure 3—Trees per acre, gross and net values estimated from individual tree data for three of the nine sample stands: Getcho, Cottonwood Ridge East, and Cottonwood Mountain.

APPENDIX D: COMPUTER PROGRAM LISTINGS

This appendix provides program listings for three computer routines necessary in predicting product potential. The programs are written in standard FORTRAN 77. A user might need to make some modifications to run the programs on a local computer, but these should be minor.

The first program produces tables of gross product alternatives by d.b.h. class. The user can define a maximum of seven products. Gross product estimates based on stand table information and chosen product alternatives can be obtained from the second program. If tree defects have been measured for a stand, the third program will give net product estimates.

Program 1—Computer Listing for Obtaining Gross Product Alternatives With User-Defined Products

```
C     PROGRAM 1

C     ********************************************************
C     GROSS PRODUCT ALTERNATIVES WITH USER-DEFINED PRODUCTS
C         PROGRAMMER : N. HERRIN
C          REVISIONS : J. SCHLIETER
C     ********************************************************

C     PROGRAM TO OBTAIN PRODUCT ALTERNATIVES FOR EACH DEFINED
C     HEIGHT CLASS IN DBH CLASSES 3 TO 7 -- USER CAN SPECIFY
C     AT MOST 7 PRODUCTS AND WILL TYPE IN NAME, LENGTH, SMALL
C     DIAM SPECS, LARGE DIAM SPECS, PRODUCT VALUE

C     UNIT ASSIGNMENTS ARE :
C          UNIT  6 = USER CONSOLE
C          UNIT 22 = OUTPUT FILE

      CHARACTER PROD(7)*10,BUTT*3,PRODUCT*3,PRO*3,DASH(7)*12,
     1RS*12,DASH2*12,VL*12,PIECE*3

      REAL SPEC(7,6),MIND(5),MAXD(5),MLEN(5,8),MINLEN(5),MAXLEN(5),
     1LDBH(10),SDBH(10),LEN(10),RESID(20),VAL,TAP(5,8)

      INTEGER NUMPROD,ICT,IPROD,LASTPROD(20),NUM(7),NPROD(7),
     1OLDALT(50,7)

C MERCHANTABLE LENGTH ARRAY -- FROM TABLE 1
      DATA((MLEN(I,J),J=1,8),I=1,5)/15.,19.,23.,27.,31.,36.,0.,0.,18.,
     *22.,26.,30.,34.,38.,42.,0.,0.,18.,22.,26.,29.,33.,37.,0.,0.,0.,
     *27.,30.,34.,38.,41.,0.,0.,0.,0.,29.,32.,36.,39.,42./

C MINIMUM DIAM ARRAY (CORRESPONDS TO DBH CLASS)
      DATA(MIND(J),J=1,5)/2.00,2.00,3.00,3.00,4.00/

C MAXIMUM DIAM ARRAY (CORRESPONDS TO DBH CLASS)
      DATA(MAXD(J),J=1,5)/3.00,4.00,5.00,6.00,7.00/

C MINIMUM TREE HEIGHT CLASS FOR EACH DBH
      DATA(MINLEN(J),J=1,5)/25.,25.,30.,35.,40./

C MAXIMUM TREE HEIGHT CLASS FOR EACH DBH
      DATA(MAXLEN(J),J=1,5)/50.,3*55.,60./

C STEM TAPER -- DEPENDS ON DBH AND HEIGHT CLASS
      DATA((TAP(I,J),J=1,8),I=1,5)/.0714,.0556,.0455,.0385,.0333,.0286,
     *0.,0.,.1144,.0893,.0713,.0595,.0511,.0455,.0405,0.,0.,.1144,.0893,
     *.0733,.0635,.0530,.0478,0.,0.,0.,.1077,.0902,.0788,.0683,.0625,0.,
     *0.,0.,0.,.1012,.0901,.0813,.0740,.0688/

      COMMON SPEC,LDBH,SDBH,LEN,NPROD,IPROD,ICT,RESID,AST,LASTPROD,
     1NUMPROD,LASTCT,NUM
      COMMON /BK1/PRODUCT,PIECE
      OPEN(6,FILE='@CONSOLE')
      OPEN(22, FILE='PRODALT.OUT',CARRIAGECONTROL='FORTRAN')

*******  INPUT PRODUCTS OR END PROGRAM  *******

    1 WRITE(6,2)
    2 FORMAT(///' Do you want to :(1)Input products  or (2)Quit ?')
      PRINT 500
  500 FORMAT('     ENTER 1 OR 2 : ',$)
```

```
      READ *,IN
      IF(IN.EQ.2) GO TO 1000
      IF(IN.NE.1.) THEN
        WRITE(6,3)
    3   FORMAT(/'  You MUST enter a 1 or 2!  Try Again!'/)
        GO TO 1
      ENDIF

******* QUERY FOR PRODUCTS AND THEIR SPECIFICATIONS  *******

      NUMPROD=0
      WRITE(6,4)
    4 FORMAT(///'  You can input up to 7 products and their specificatio
     1ns.'/'  The specifications are:'/'    -NAME'/'    -LENGTH'/'    -S
     2MALL diameter constraints -  min  and  max  constraint'/'    -LARG
     3E diameter constraints -  min  and  max  constraint'/'    -VALUE o
     4f product'//)
   10 NUMPROD=NUMPROD + 1
      IF(NUMPROD.GT.7) THEN
         NUMPROD=7
         GO TO 19
      ENDIF
      WRITE(6,11) NUMPROD
   11 FORMAT(//'   Enter Specifications for Product #',I1/)
      PRINT 505
  505 FORMAT('     ENTER PRODUCT NAME(10 CHAR OR LESS) : ',$)
      READ(*,12) PROD(NUMPROD)
   12 FORMAT(A10)
      IF(PROD(NUMPROD).EQ.'     ') THEN
        IF(NUMPROD.EQ.1) GO TO 1
        NUMPROD=NUMPROD - 1
        GO TO 19
      ENDIF
      PRINT 510
  510 FORMAT(5X,'ENTER PRODUCT LENGTH : ',$)
      READ *,SPEC(NUMPROD,1)
      WRITE(6,13)
   13 FORMAT('     Enter SMALL Diameter Specifications:')
      PRINT 515
  515 FORMAT(8X,'MIN,MAX : ',$)
      READ *, SPEC(NUMPROD,2),SPEC(NUMPROD,3)
      WRITE(6,14)
   14 FORMAT('     Enter LARGE Diameter Specifications:')
      PRINT 515
      READ *,SPEC(NUMPROD,4),SPEC(NUMPROD,5)

******* ROUND-OFFS FOR OUR PRODUCTS MAY NOT BE NEEDED BY OTHERS
      SPEC(NUMPROD,1)=SPEC(NUMPROD,1) - .04
      SPEC(NUMPROD,2)=SPEC(NUMPROD,2) - .04
      SPEC(NUMPROD,4)=SPEC(NUMPROD,4) - .04
      SPEC(NUMPROD,3)=SPEC(NUMPROD,3) + .05
      SPEC(NUMPROD,5)=SPEC(NUMPROD,5) + .05

      PRINT 525
  525 FORMAT('     ENTER PRODUCT VALUE : ',$)
      READ *,SPEC(NUMPROD,6)
      GO TO 10

C  INITIALIZE ARRAY COUNTERS : ICL=DBH CLASS, IFT=LENGTH, ICT=UNUSED
C    ARRAY COUNTER, IPROD=PRODUCT #, BUTT=BUTT END OF LOG, NALT= # OF
C    ALTERNATIVES PER HGT, NUMALT=COUNTER FOR ALTERNATIVE ARRAY OLDALT
```

```
   19 ICL=1
      IFT=1
      ICT=1
      IPROD=1
      BUTT='YES'
      NALT=0
      NUMALT=0

*******  WRITE HEADER  *******

      WRITE(22,20) MAXD(ICL)
   20 FORMAT('1    DBH CLASS ',F4.2//)
      RS=' RESIDUAL '
      VL='   VALUE  '
      DASH2='----------  '
      WRITE(22,25) (PROD(I),I=1,NUMPROD),RS,VL
   25 FORMAT(' HGT ALT  ',7(A10,2X),A10,2X,A10)
      DO 26 J=1,NUMPROD
        DASH(J)='----------  '
   26 CONTINUE
      WRITE(22,30) (DASH(I),I=1,NUMPROD),DASH2,DASH2
   30 FORMAT(' --- ---   ',7(A12),A12,A12/)

*******  PUT LOG INTO UNUSED ARRAY
*******       LDBH=LARGE END  SDBH=SMALL END  LEN=LENGTH
      LDBH(ICT)=MAXD(ICL)
      SDBH(ICT)=MIND(ICL)
   60 LEN(ICT)=MLEN(ICL,IFT)
      IF(LEN(ICT).EQ.0.) THEN
         IFT=IFT+1
         GO TO 60
      ENDIF

   75 BUTT='YES'
      PRODUCT='NO'
      PIECE='NO'
      DO 76 M=1,20
       LASTPROD(M)=0
       RESID(M)=0.0
   76 CONTINUE

C REDUCE MERCH LENGTH ONE FT ON BUTT END TO AVOID SWELL
      LEN(ICT)=LEN(ICT) - 1.0

C CALCULATE RESIDUAL VOLUME -- RESID
      VOL=(LDBH(ICT)**2) + (SDBH(ICT)**2)
      RESID(ICT)=.002727077*VOL*LEN(ICT)

      AST=TAP(ICL,IFT)
      VAL=0.0
      DO 80 J=1,NUMPROD
         NPROD(J)=0
   80 CONTINUE

C CALL SUBROUTINE SCAN TO SEE IF PRODUCT FITS
   90 PRO='NO'
   95 CALL SCAN

*******     IF PRODUCT FIT, CALL SCAN AGAIN TO SEE IF ANY PRODUCTS
*******     WILL FIT IN LEFTOVER PIECE
```

```
  110 IF(PRODUCT.EQ.'YES') THEN
        IPROD=1
        PRODUCT='NO'
        PRO='YES'
        CALL SCAN
        GO TO 110
      ELSE
        IF(PRO.EQ.'YES') THEN
          IF(IPROD.EQ.NUMPROD) GO TO 200
          IPROD=IPROD+1
          GO TO 95
        ENDIF
      ENDIF

******* NEXT PRODUCT, BUT FIRST WRITE THE ALTERNATIVE OBTAINED
  200  IF(PRO.EQ.'NO') GO TO 235
         NUMALT=NUMALT+1
         VAL=0.0
         IF(RESID(ICT).LT.0.0) RESID(ICT)=0.0
         DO 205 I=1,NUMPROD
           OLDALT(NUMALT,I)=NPROD(I)
           VAL=VAL+(FLOAT(OLDALT(NUMALT,I))*SPEC(I,6))
  205    CONTINUE
         IF(NALT.EQ.0) THEN
           NALT=NALT+1
           WRITE(22,210)MINLEN(ICL),NALT,(FLOAT(NPROD(I)),I=1,NUMPROD),
     1RESID(ICT),VAL
  210      FORMAT(/' ',F3.0,' ',I3,2X,8(F7.2,5X),F7.2)
         ELSE

C SEE IF ALTERNATIVE ALREADY EXISTS
           DO 220 J=1,NUMALT-1
             DO 215 I=1,NUMPROD
               IF(NPROD(I).EQ.OLDALT(J,I)) GO TO 215
               GO TO 220
  215        CONTINUE
             GO TO 235
  220      CONTINUE
           NALT=NALT+1
           WRITE(22,225)NALT,(FLOAT(NPROD(I)),I=1,NUMPROD),RESID(ICT),
     1VAL
  225      FORMAT('     ',I3,2X,8(F7.2,5X),F7.2)
         ENDIF
      IF(ICT.GE.2) THEN
        IF(PRO.EQ.'NO') GO TO 235
        ICT=ICT-1
        J=LASTPROD(ICT)
        NPROD(J)=NPROD(J) - 1
        IF(ICT.EQ.1) THEN
          DO 226 J=1,NUMPROD
            NPROD(J)=0
  226     CONTINUE
        ENDIF
        IF(IPROD.GE.NUMPROD) GO TO 238
  235   IF(IPROD.GE.NUMPROD) THEN
          IF(ICT.EQ.1) THEN
           DO 236 J=1,NUMPROD
            NPROD(J)=0
  236      CONTINUE
           GO TO 238
          ENDIF
          J=LASTPROD(ICT-1)
          NPROD(J)=NPROD(J) - 1
          ICT=ICT-1
          IPROD=LASTPROD(ICT)+1
          IF(IPROD.GT.NUMPROD) GO TO 240
          IF(PIECE.EQ.'YES') THEN
            IF(ICT.LT.LASTCT) THEN
              PIECE='NO'

******* TAKE AWAY ALL PRODUCTS MADE FROM SPLIT LOG
              DO 237 K=1,NUMPROD
                NPROD(K)=NPROD(K) - NUM(K)
  237         CONTINUE
            ENDIF
          ENDIF
          GO TO 239
       ENDIF
  238  IF(PRO.EQ.'NO') THEN
          IPROD=IPROD+1
          IF(IPROD.GT.NUMPROD) GO TO 240
          GO TO 239
       ENDIF
       IPROD=LASTPROD(ICT)+1
  239  GO TO 90
     ENDIF

*******  GO TO NEXT HEIGHT CLASS
  240    IPROD=1
         NALT=0
         NUMALT=0
         IFT=IFT+1
         MINLEN(ICL)=MINLEN(ICL)+5.
  250    IF(IFT.GT.8) THEN

*******  GO TO NEXT DBH CLASS
            IFT=1
            ICL=ICL+1
            IF(ICL.GT.5) GO TO 1000

*******  WRITE HEADINGS
            WRITE(22,20) MAXD(ICL)
            WRITE(22,25) (PROD(I),I=1,NUMPROD),RS,VL
            WRITE(22,30) (DASH(I),I=1,NUMPROD),DASH2,DASH2
         ENDIF

*******  PUT LOG INTO ARRAY
     ICT=1
     LDBH(ICT)=MAXD(ICL)
     SDBH(ICT)=MIND(ICL)
  270 LEN(ICT)=MLEN(ICL,IFT)
     IF(LEN(ICT).EQ.0.) THEN
       IFT=IFT+1
       IF(IFT.GT.8) GO TO 250
       GO TO 270
     ENDIF
     GO TO 75

 1000 STOP
     END
```

```
      SUBROUTINE SCAN

C          THIS SUBROUTINE SCANS FOR PRODUCTS

      CHARACTER PRODUCT*3,PRO*3,PIECE*3

      REAL SPEC(7,6),RESID(20),DIVL(2),DIVS(2),DIVLN(2),
     1LDBH(10),SDBH(10),LEN(10),L,TAP(5,8)

      INTEGER ICT,NUMPROD,IPROD,LASTPROD(20),NUM(7),NPROD(7)

      COMMON SPEC,LDBH,SDBH,LEN,NPROD,IPROD,ICT,RESID,AST,LASTPROD,
     1NUMPROD,LASTCT,NUM
      COMMON /BK1/PRODUCT,PIECE

      J=IPROD

C CHECK IF LARGE DIAMETER WITHIN PRODUCT SPECS
  370 IF((LDBH(ICT).LE.SPEC(J,5)).AND.(LDBH(ICT).GE.SPEC(J,4)))
     1THEN

C CHECK LENGTH TO SEE IF PRODUCT FITS
       IF(LEN(ICT).GE.SPEC(J,1)) THEN

C IF LENGTH EQUALS PRODUCT LENGTH, MAKE SURE SMALL DIAM IS LARGER
C THAN MINIMUM SMALL DIAM
        IF(LEN(ICT).EQ.SPEC(J,1)) THEN
          IF(SDBH(ICT).LT.SPEC(J,2)) GO TO 425
        ENDIF

C CALCULATE SMALL DIAM AT PRODUCT LENGTH
          D1=LDBH(ICT)-(SPEC(J,1)*AST)
          IF(D1.LT.SDBH(ICT))D1=SDBH(ICT)

C CHECK TO SEE IF SMALL DIAM WITHIN PRODUCT SPECS
          IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN

C TAKE PRODUCT OUT OF PIECE
             LDBH(ICT+1)=D1
             SDBH(ICT+1)=SDBH(ICT)
             LEN(ICT+1)=LEN(ICT)-SPEC(J,1)
             V1=(LDBH(ICT)**2) + (D1**2)
             RESID(ICT+1)=RESID(ICT)- (.002727077*V1*SPEC(J,1))
             NPROD(J)=NPROD(J) + 1
             LASTPROD(ICT)=J
             ICT=ICT+1
             PRODUCT='YES'
             GO TO 600
           ELSE

C IF SMALL DIAM STILL TOO BIG, TAKE AWAY 1 FOOT AND TRY AGAIN
             IF(D1.GT.SPEC(J,3)) THEN
                LDBH(ICT)=LDBH(ICT)-AST
                LEN(ICT)=LEN(ICT)-1.0
                GO TO 370
             ENDIF
           ENDIF
        ENDIF
      ELSE

C CHECK TO SEE IF PIECE NEEDS TO BE DIVIDED -- IF SMALL DIAM GREATER
```

```
C THAN MAX LARGE DIAM OF PRODUCT, NO PRODUCT CAN BE MADE FROM PIECE
    IF(SDBH(ICT).GT.SPEC(J,5)) GO TO 425

C CHECK TO SEE IF LARGE DIAM GREATER THAN MIN LARGE DIAM
    IF(LDBH(ICT).GT.SPEC(J,4)) THEN

C CHECK LENGTH TO SEE IF IT FITS
     IF(LEN(ICT).GE.SPEC(J,1)) THEN

C DETERMINE LENGTH AT MAX LARGE DIAM -- SPEC(J,5)
      L=(LDBH(ICT)-SPEC(J,5))/AST
      IF((LEN(ICT)-L).LT.SPEC(J,1)) GO TO 425

C DIVIDE THE PIECE
      DIVL(1)=LDBH(ICT)
      DIVS(1)=SPEC(J,5)
      DIVLN(1)=L
      DIVL(2)=SPEC(J,5)
      DIVS(2)=SDBH(ICT)
      DIVLN(2)=LEN(ICT)-L

C CHECK AGAIN TO SEE IF PRODUCT WILL FIT
 400  IF((DIVL(2).LE.SPEC(J,5)).AND.(DIVL(2).GE.SPEC(J,4))) THEN
        IF(DIVLN(2).GE.SPEC(J,1)) THEN
         D1=DIVL(2)-(SPEC(J,1)*AST)
         IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN
          LDBH(ICT+1)=D1
          SDBH(ICT+1)=SDBH(ICT)
          LEN(ICT+1)=DIVLN(2)-SPEC(J,1)
          V2=(DIVL(2)**2) + (D1**2)
          RESID(ICT+1)=RESID(ICT)- (.002727077*V2*SPEC(J,1))
          NPROD(J)=NPROD(J) + 1
          LASTPROD(ICT)=J
          ICT=ICT+1
          LASTCT=ICT
          PRODUCT='YES'
          GO TO 450
         ELSE

C IF LARGE DIAM TOO BIG, TAKE AWAY 1 FOOT AND TRY AGAIN
          IF(D1.GT.SPEC(J,3)) THEN
           DIVLN(1)=DIVLN(1)+1
           DIVLN(2)=DIVLN(2)-1
           DIVL(2)=DIVL(2)-AST
           DIVS(1)=DIVL(2)
           GO TO 400
          ENDIF
         ENDIF
        ENDIF
      ENDIF
     ENDIF
    ENDIF
   ENDIF
 425 PRODUCT='NO'
   GO TO 600


******* CHECK PIECE 1 FOR PRODUCT -- INITIALIZE THE NUMBER OF
******* PRODUCTS TAKEN OUT OF PIECE

 450 J=1
```

```
      DO 460 K=1,NUMPROD
        NUM(K)=0
  460 CONTINUE
  475 IF((DIVL(1).LE.SPEC(J,5)).AND.(DIVL(1).GE.SPEC(J,4))) THEN
        IF(DIVLN(1).GE.SPEC(J,1)) THEN
          D1=DIVL(1)-(SPEC(J,1)*AST)
          IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN

C TAKE PRODUCT OUT AND CHECK REMAINING PIECE FOR PRODUCTS

            V3=(DIVL(1)**2) + (D1**2)
            RESID(ICT)=RESID(ICT)- (.002727077*V3*SPEC(J,1))
            PIECE='YES'
            DIVL(1)=D1
            DIVLN(1)=DIVLN(1)-SPEC(J,1)
            NPROD(J)=NPROD(J) + 1
            NUM(J)=NUM(J)+1
            GO TO 475
          ENDIF
        ENDIF
      ENDIF
      J=J+1
      IF(J.GT.NUMPROD) GO TO 600
      GO TO 475


  600 RETURN
      END
```

Program 2—Computer Listing for Obtaining Gross Product Estimates From Stand Table Data

```
C     PROGRAM 2
C
C    ***********************************************
C      GROSS PRODUCT POTENTIAL FROM A STAND TABLE
C          PROGRAMMER : J.SCHLIETER
C    ***********************************************
C
C     PROGRAM TO OBTAIN GROSS PRODUCT ESTIMATES FROM STAND
C     TABLE DATA -- THE USER NEEDS :
C                      1. STAND TABLE WITH AVERAGE TOTAL TREE
C                         HEIGHT AND STEMS/ACRE FOR EACH DBH
C                         CLASS
C
C                      2. GROSS PRODUCT ALTERNATIVE TABLES AS
C                         IN APPENDIX A -- USING AVERAGE TOTAL
C                         TREE HEIGHT, SELECT AN ALTERNATIVE FOR
C                         EACH DBH CLASS
C
C                      3. VALUES OF THE PRODUCTS (MAX OF 7)
C
C
C     NOTE:A WORKSHEET TO ASSIST THE USER IS GIVEN AT THE END
C          OF THE PROGRAM LISTING
C
C          UNIT ASSIGNMENTS ARE :
C             UNIT  6 = USER CONSOLE
C             UNIT 22 = OUTPUT FILE
C
C               ******************************
C                  DEFINITIONS OF VARIABLES
C               ******************************
C
C          COST(J)   = USER-ASSIGNED VALUE FOR PRODUCT J
C          NAME1,2,3 = STAND NAME (8 CHARACTERS IN EACH)
C          VGT       = TOTAL VALUE FOR STAND
C          TOTRV     = TOTAL RESIDUAL VOLUME FOR STAND
C          NTOT(J)   = TOTAL NO. OF PRODUCT J IN STAND
C          VTOT(J)   = TOTAL VALUE FOR PRODUCT J IN STAND
C          NP(I,J)   = NUMBER OF PRODUCT J IN DBH CLASS I
C          VOL(I)    = RESIDUAL VOLUME IN DBH I FOR ALTERNATIVE
C          NS(I)     = STEMS/ACRE FOR DBH CLASS I FROM STAND TABLE
C          N(I,J)    = NO./ACRE OF PRODUCT J IN DBH CLASS I
C          V(I,J)    = VALUE/ACRE OF PRODUCT J IN DBH CLASS I
C          RV(I)     = RESIDUAL VOLUME IN DBH CLASS I
C               ******************************
C
      DIMENSION COST(7),V(5,7),RV(5),VTOT(7),N(5,7),NTOT(7)
      DOUBLE PRECISION NAME1(8),NAME2(8),NAME3(8)
      COMMON NP(5,7),VOL(5),NS(5)
      OPEN(6,FILE='@CONSOLE')
      OPEN(22, FILE='GROSS.OUT',CARRIAGECONTROL='FORTRAN')
C
C     ENTER PRODUCT VALUES AT RUN TIME--THESE REMAIN FIXED
C     FOR THE ENTIRE RUN
C
      WRITE(6,30)
   30 FORMAT(2X,'TYPE 7 PRODUCT VALUES SEPARATED BY COMMAS')
      PRINT 35
   35 FORMAT('       VALUES : ',$)
      READ *, (COST(J),J=1,7)
```

```
C
C     INITIALIZE -- PROGRAM BEGINS HERE FOR EACH STAND --
C
   10 VGT=0.0
      TOTRV=0.0
      DO 20 J=1,7
          NTOT(J)=0
   20     VTOT(J)=0.0
C
C     INPUT INFORMATION FOR A PARTICULAR STAND
C
      WRITE(6,50)
   50 FORMAT(/2X,'STAND NAME--MAX OF 24 CHARACTERS : ',$)
      READ(*,60)NAME1,NAME2,NAME3
   60 FORMAT(3(8A1))
C
      I=1
   70 CALL INFO(I,NP(I,J),VOL(I),NS(I))
      IF(I.EQ.5)GO TO 75
      I=I + 1
      GO TO 70

C
C     PER ACRE CALCULATIONS AND TOTALS FOR STAND
C
   75 DO 90 I=1,5
      RV(I)=VOL(I)*NS(I)
          DO 80 J=1,7
          N(I,J)=NP(I,J)*NS(I)
   80     V(I,J)=N(I,J)*COST(J)
   90 CONTINUE
C
      DO 110 J=1,7
          DO 100 I=1,5
          NTOT(J)=NTOT(J) + N(I,J)
  100     VTOT(J)=VTOT(J) + V(I,J)
  110 CONTINUE
C
      DO 120 J=1,7
  120 VGT=VGT + VTOT(J)
C
      DO 130 I=1,5
  130 TOTRV=TOTRV + RV(I)
C
C     THESE INITIALIZATIONS WERE SPECIFIC TO OUR CONSTRAINTS
C     AND MAY NOT BE NEEDED
C
      NP(1,7)=0
      NP(2,7)=0
      DO 150 I=3,4
          DO 140 J=5,7
  140     NP(I,J)=0
  150 CONTINUE
      NP(5,5)=0
      NP(5,6)=0
C
C     WRITE THE OUTPUT FOR THE STAND
C
      WRITE(22,310) (NAME1(J),J=1,8),(NAME2(J),J=1,8),
     1(NAME3(J),J=1,8)
  310 FORMAT('1'//4X,'STAND EVALUATION --',4X,3(8A1)/
     14X,'GROSS PRODUCT POTENTIAL'//)
      WRITE(22,315)
  315 FORMAT(11X,'7-FT',5X,'13-FT',5X,'17-FT',5X,'21-FT',5X,'10-FT',
     15X,'PANEL',6X,'BARN',7X,'RES')
      WRITE(22,320)
  320 FORMAT(1X,'DBH',7X,'POST',3(6X,'RAIL'),6X,'PROP',2(6X,'POLE'),
     16X,'VOLUME')
      WRITE(22,325)
  325 FORMAT(1X,3('-'),2X,7(4X,6('-')),4X,7('-'))
      WRITE(22,330)
  330 FORMAT(10X,'PROD 1',4X,'PROD 2',4X,'PROD 3',4X,'PROD 4',
     14X,'PROD 5',4X,'PROD 6',4X,'PROD 7')
      WRITE(22,335)
  335 FORMAT(6X,7(4X,6('-'))/)
C
      DO 370 I=1,5
      K=I + 2
      WRITE(22,340) K,(N(I,J),J=1,7),RV(I)
  340 FORMAT(2X,I1,2X,'#',7(4X,I6),4X,F7.2)
      WRITE(22,350) (V(I,J),J=1,7)
  350 FORMAT(5X,'$',7(3X,F7.2)/)
  370 CONTINUE
C
      WRITE(22,380) (NTOT(J),J=1,7),TOTRV
  380 FORMAT(//1X,'TOT',1X,'#',7(3X,I7),3X,F8.2)
      WRITE(22,385) (VTOT(J),J=1,7)
  385 FORMAT(5X,'$',7(3X,F7.2))
      WRITE(22,390) VGT
  390 FORMAT(////5X,'TOTAL VALUE FOR STAND -- ',F7.2)
C
C     RECYCLE FOR ANOTHER STAND -- OR QUIT
      WRITE(6,395)
  395 FORMAT(/5X,'ANOTHER STAND? YES=1 OR NO=2 : ',$)
      READ *,IRUN
      IF(IRUN.EQ.1) GO TO 10
      END
C
      SUBROUTINE INFO(II,NPP,VOLL,NSS)
C
C           THIS SUBROUTINE QUERIES THE USER FOR THE INPUT
C           INFORMATION FOR A PARTICULAR STAND--IT DOES THIS
C           FOR EACH DBH CLASS
C
      COMMON NP(5,7),VOL(5),NS(5)
      K=II + 2
      WRITE(6,400) K
  400 FORMAT(/5X,'INPUT FOR ',I1,'-INCH CLASS')
      WRITE(6,410)
  410 FORMAT(7X,'ENTER 7 PRODUCT COUNTS SEPARATED BY COMMAS : ',$)
      READ *,(NP(II,J),J=1,7)

      WRITE(6,430)
  430 FORMAT(10X,'ENTER RESIDUAL VOL FOR ALTERNATIVE : ',$)
      READ *,VOL(II)

      WRITE(6,450)
  450 FORMAT(10X,'ENTER STEMS/ACRE FOR THIS DBH CLASS : ',$)
      READ *,NS(II)
      RETURN
      END
```

```
********************************
   WORKSHEET FOR PROGRAM 2
********************************

PRODUCT VALUES : VALUES THE USER ASSIGNS TO THE
                 7 PRODUCTS--MUST BE IN SAME ORDER AS
                 IN THE PRODUCT ALTERNATIVES
                X.XX,X.XX,X.XX,X.XX,X.XX,X.XX,X.XX

       WE USED : .52,.65,1.24,1.45,.50,.50,2.38


3-INCH CLASS    : AVERAGE TOTAL TREE HEIGHT=______
                  HEIGHT CLASS=______ (SEE BELOW)
                  ALTERNATIVE SELECTED=______
       PRODUCT COUNTS FOR CHOSEN ALTERNATIVE IN SAME ORDER
       AS PRODUCT VALUES-- X,X,X,X,X,X,X
            RESIDUAL VOLUME FOR ALTERNATIVE=______(X.XX)
            STEMS/ACRE FROM STAND TABLE=______(XXXX)

4-INCH CLASS    : AVERAGE TOTAL TREE HEIGHT=______
                  HEIGHT CLASS=______ (SEE BELOW)
                  ALTERNATIVE SELECTED=______
       PRODUCT COUNTS FOR CHOSEN ALTERNATIVE IN SAME ORDER
       AS PRODUCT VALUES-- X,X,X,X,X,X,X
            RESIDUAL VOLUME FOR ALTERNATIVE=______(X.XX)
            STEMS/ACRE FROM STAND TABLE=______(XXXX)

5-INCH CLASS    : AVERAGE TOTAL TREE HEIGHT=______
                  HEIGHT CLASS=______ (SEE BELOW)
                  ALTERNATIVE SELECTED=______
       PRODUCT COUNTS FOR CHOSEN ALTERNATIVE IN SAME ORDER
       AS PRODUCT VALUES-- X,X,X,X,X,X,X
            RESIDUAL VOLUME FOR ALTERNATIVE=______(X.XX)
            STEMS/ACRE FROM STAND TABLE=______(XXXX)

6-INCH CLASS    : AVERAGE TOTAL TREE HEIGHT=______
                  HEIGHT CLASS=______ (SEE BELOW)
                  ALTERNATIVE SELECTED=______
       PRODUCT COUNTS FOR CHOSEN ALTERNATIVE IN SAME ORDER
       AS PRODUCT VALUES-- X,X,X,X,X,X,X
            RESIDUAL VOLUME FOR ALTERNATIVE=______(X.XX)
            STEMS/ACRE FROM STAND TABLE=______(XXXX)

7-INCH CLASS    : AVERAGE TOTAL TREE HEIGHT=______
                  HEIGHT CLASS=______ (SEE BELOW)
                  ALTERNATIVE SELECTED=______
       PRODUCT COUNTS FOR CHOSEN ALTERNATIVE IN SAME ORDER
       AS PRODUCT VALUES-- X,X,X,X,X,X,X
            RESIDUAL VOLUME FOR ALTERNATIVE=______(X.XX)
            STEMS/ACRE FROM STAND TABLE=______(XXXX)

HEIGHT CLASSES DEFINED :
----------------------

        25 = 22.5-27.4          45 = 42.5-47.4
        30 = 27.5-32.4          50 = 47.5-52.4
        35 = 32.5-37.4          55 = 52.5-57.4
        40 = 37.5-42.4          60 = 57.5-62.4
```

Program 3—Computer Listing for Obtaining Net Product Estimates From Individual Tree Records

```
C     PROGRAM 3

C     ********************************************************
C     NET PRODUCT POTENTIAL FROM INDIVIDUAL PIECES AFTER ALL
C                 DEFECTS HAVE BEEN REMOVED
C         PROGRAMMER : J. SCHLIETER
C     ********************************************************

C     PROGRAM TO OBTAIN NET PRODUCT ESTIMATES FOR THOSE PIECES
C     REMAINING AFTER DEFECTS ARE ELIMINATED -- USER CAN SPECIFY
C     AT MOST 7 PRODUCTS AND WILL TYPE IN NAME, LENGTH, SMALL
C     DIAM SPECS, LARGE DIAM SPECS, PRODUCT VALUE -- USER MUST
C     DO SOME PRELIMINARY WORK TO CREATE THE DATA FILE NEEDED
C     FOR THIS ROUTINE!   (DETAILS FOLLOW THIS LISTING)

C     UNIT ASSIGNMENTS ARE :
C          UNITS 5,6 = USER CONSOLE      UNIT 21 = SCRATCH FILE
C          UNIT 20 = INPUT DATA FILE     UNIT 22 = OUTPUT FILE

      CHARACTER PROD(7)*10,PRODUCT*3,PRO*3,PIECE*3

      DIMENSION SPEC(7,6),SDBH(10),RESID(5),VALTOT(5),LASTPROD(20),NUM(7
     1),NPROD(7),IPR(5,7),PR(5,7),NP(5),BEG(10)
      REAL LDBH(10),LEN(10)
      INTEGER OLDALT(50,7)

      COMMON SPEC,LDBH,SDBH,LEN,NPROD,IPROD,ICT,RES,AST,LASTPROD,
     1NUMPROD,LASTCT,NUM,ICL,BEG
      COMMON /BK1/PRODUCT,PIECE

      OPEN(6,FILE='@CONSOLE')
      OPEN(20,FILE='DEFECT.DAT')
      OPEN(21,FILE='INTER.DAT')
      OPEN(22,FILE='NET.OUT',CARRIAGECONTROL='FORTRAN')

*******  INPUT PRODUCTS OR END PROGRAM  *******

    1 WRITE(6,2)
    2 FORMAT(///' Do you want to :(1)Input products  or (2)Quit ?')
      PRINT 500
  500 FORMAT('     ENTER 1 OR 2 : ',$)
      READ *,IN
      IF(IN.EQ.2) GO TO 1000
      IF(IN.NE.1) THEN
        WRITE(6,3)
    3   FORMAT(/'  You MUST enter a 1 or 2!  Try Again!'/)
        GO TO 1
      ENDIF

*******  QUERY FOR PRODUCTS AND THEIR SPECIFICATIONS  *******

      NUMPROD=0
      WRITE(6,4)
    4 FORMAT(///' You can input up to 7 products and their specificatio
     1ns.'/' The specifications are:'/'    -NAME'/'    -LENGTH'/'    -S
     2MALL diameter constraints -  min  and  max  constraint'/'    -LARG
     3E diameter constraints -  min  and  max  constraint'/'    -VALUE o
     4f product'//)
   10 NUMPROD=NUMPROD + 1
      IF(NUMPROD.GT.7) THEN
         NUMPROD=7
         GO TO 17
      ENDIF
      WRITE(6,11) NUMPROD
   11 FORMAT(//'   Enter Specifications for Product #',I1/)
      PRINT 505
  505 FORMAT('     ENTER PRODUCT NAME(10 CHAR OR LESS) : ',$)
      READ(5,12) PROD(NUMPROD)
   12 FORMAT(A10)
      IF(PROD(NUMPROD).EQ.'          ') THEN
        IF(NUMPROD.EQ.1) GO TO 1
        NUMPROD=NUMPROD - 1
        GO TO 17
      ENDIF
      PRINT 510
  510 FORMAT(5X,'ENTER PRODUCT LENGTH :',$)
      READ(5,*) SPEC(NUMPROD,1)
      WRITE(6,13)
   13 FORMAT(5X,'Enter SMALL Diameter Specifications:')
      PRINT 515
  515 FORMAT(8X,'MIN,MAX :',$)
      READ(5,*) SPEC(NUMPROD,2),SPEC(NUMPROD,3)
      WRITE(6,14)
   14 FORMAT(5X,'Enter LARGE Diameter Specifications:')
      PRINT 515
      READ(5,*) SPEC(NUMPROD,4),SPEC(NUMPROD,5)

******* ROUND-OFFS FOR OUR PRODUCTS MAY NOT BE NEEDED BY OTHERS
      SPEC(NUMPROD,1)=SPEC(NUMPROD,1) - .04
      SPEC(NUMPROD,2)=SPEC(NUMPROD,2) - .04
      SPEC(NUMPROD,4)=SPEC(NUMPROD,4) - .04
      SPEC(NUMPROD,3)=SPEC(NUMPROD,3) + .05
      SPEC(NUMPROD,5)=SPEC(NUMPROD,5) + .05

      PRINT 525
  525 FORMAT(5X,'ENTER PRODUCT VALUE :',$)
      READ(5,*) SPEC(NUMPROD,6)
      GO TO 10

*******  READ STAND INFO FROM DATA FILE
   17 READ(20,530,ERR=1000) ISTAND,NPLOT,BLOW
  530 FORMAT(2(I1,1X),F3.0)

      DO 6 I=1,5
         RESID(I)=0.0
         NP(I)=0
         VALTOT(I)=0.0
         DO 5 J=1,7
            IPR(I,J)=0
    5    CONTINUE
    6 CONTINUE
*******  READ INFO ON A DEFECTIVE PIECE -- RETURN HERE AFTER
*******  PRODUCT ALTERNATIVE DETERMINED FOR PIECE
   19 READ(20,535,ERR=250) ICL,DL,DS, B1,ALEN,AST,RESV
  535 FORMAT(I1,2(2X,F4.2),2(2X,F4.1),2X,F4.3,1X,F4.2)
      RES=0.0

C  INITIALIZE COUNTERS : ICL=DBH CLASS, ICT=UNUSED ARRAY COUNTER, IPROD=
C    PRODUCT #, NALT=# OF ALTERNATIVES/PIECE, NUMALT=COUNTER FOR OLDALT

      ICL=ICL - 2
      NP(ICL)=NP(ICL) + 1
      ICT=1
      IPROD=1
      NALT=0
      NUMALT=0

*******  PUT LOG INTO UNUSED ARRAY
*******      LDBH=LARGE END  SDBH=SMALL END  LEN=LENGTH
      LDBH(ICT)=DL
      SDBH(ICT)=DS
      LEN(ICT)=ALEN
      BEG(ICT)=B1

      PRODUCT='NO'
      PIECE='NO'
      DO 76 M=1,20
       LASTPROD(M)=0
   76 CONTINUE

      VAL=0.0
      DO 80 J=1,NUMPROD
         NPROD(J)=0
   80 CONTINUE

C CALL SUBROUTINE SCAN TO SEE IF PRODUCT FITS
   90 PRO='NO'
   95 CALL SCAN

*******     IF PRODUCT FIT, CALL SCAN AGAIN TO SEE IF ANY PRODUCTS
*******     WILL FIT IN LEFTOVER PIECE
  110 IF(PRODUCT.EQ.'YES') THEN
        IPROD=1
        PRODUCT='NO'
        PRO='YES'
        CALL SCAN
        GO TO 110
      ELSE
        IF(PRO.EQ.'YES') THEN
          IF(IPROD.EQ.NUMPROD) GO TO 200
          IPROD=IPROD+1
          GO TO 95
        ENDIF
      ENDIF

******* NEXT PRODUCT, BUT FIRST WRITE THE ALTERNATIVE OBTAINED
  200  IF(PRO.EQ.'NO') GO TO 235
         NUMALT=NUMALT+1
         VAL=0.0
         IF(RES.LT.0.0)RES=0.0
         DO 205 I=1,NUMPROD
           OLDALT(NUMALT,I)=NPROD(I)
           VAL=VAL+(FLOAT(OLDALT(NUMALT,I))*SPEC(I,6))
  205    CONTINUE
         IF(NALT.EQ.0) THEN
           NALT=NALT+1
           WRITE(21,210)NALT,(NPROD(I),I=1,NUMPROD),RES,VAL,NP(ICL)
  210      FORMAT(1X,8(I3,2X),2(F6.2,2X),I2)
         ELSE

C SEE IF ALTERNATIVE ALREADY EXISTS
           DO 220 J=1,NUMALT-1
             DO 215 I=1,NUMPROD
```

```
               IF(NPROD(I).EQ.OLDALT(J,I)) GO TO 215
               GO TO 220
  215        CONTINUE
             GO TO 235
  220      CONTINUE
           NALT=NALT+1
           WRITE(21,210)NALT,(NPROD(I),I=1,NUMPROD),RES,VAL,NP(ICL)
         ENDIF
      IF(ICT.GE.2) THEN
        IF(PRO.EQ.'NO') GO TO 235
        ICT=ICT-1
        J=LASTPROD(ICT)
        NPROD(J)=NPROD(J) - 1
         IF(ICT.EQ.1) THEN
          DO 226 J=1,NUMPROD
            NPROD(J)=0
  226     CONTINUE
        ENDIF
        IF(IPROD.GE.NUMPROD) GO TO 238
  235   IF(IPROD.GE.NUMPROD) THEN
          IF(ICT.EQ.1) THEN
           DO 236 J=1,NUMPROD
            NPROD(J)=0
  236      CONTINUE
        V2=0.0
        NALT=NALT + 1
        WRITE(21,210)NALT,(NPROD(I),I=1,NUMPROD),RESV,V2,NP(ICL)
           GO TO 238
          ENDIF
           J=LASTPROD(ICT-1)
           NPROD(J)=NPROD(J) - 1
           ICT=ICT-1
           IPROD=LASTPROD(ICT)+1
           IF(IPROD.GT.NUMPROD) GO TO 240
           IF(PIECE.EQ.'YES') THEN
             IF(ICT.LT.LASTCT) THEN
               PIECE='NO'

******* TAKE AWAY ALL PRODUCTS MADE FROM SPLIT LOG
               DO 237 K=1,NUMPROD
                 NPROD(K)=NPROD(K) - NUM(K)
  237          CONTINUE
             ENDIF
           ENDIF
           GO TO 239
        ENDIF
  238   IF(PRO.EQ.'NO') THEN
           IPROD=IPROD+1
           IF(IPROD.GT.NUMPROD) GO TO 240
           GO TO 239
        ENDIF
        IPROD=LASTPROD(ICT)+1
  239   GO TO 90
      ENDIF

*******  CHOOSE ALTERNATIVE, UPDATE ICL ARRAYS, PREPARE TO READ
*******  INFO FOR NEXT PIECE
  240 REWIND 21
      V=0.0
      R=0.0
      DO 242 I=1,NALT
```

```
        READ(21,210)K,KP1,KP2,KP3,KP4,KP5,KP6,KP7,RES,VK,KK
        IF(ICL.GE.3 .AND. KP5.GT.0) GO TO 242
        IF(VK.EQ.0.0 .AND. K.EQ.1) GO TO 247
        IF(VK.EQ.V) GO TO 243
        IF(VK.LT.V) GO TO 242
        GO TO 244
  243 IF(RES.GT.R) GO TO 242
  244   KPR1=KP1
        KPR2=KP2
        KPR3=KP3
        KPR4=KP4
        KPR5=KP5
        KPR6=KP6
        KPR7=KP7
        V=VK
        R=RES
  242 CONTINUE

      IPR(ICL,1)=IPR(ICL,1) + KPR1
      IPR(ICL,2)=IPR(ICL,2) + KPR2
      IPR(ICL,3)=IPR(ICL,3) + KPR3
      IPR(ICL,4)=IPR(ICL,4) + KPR4
      IPR(ICL,5)=IPR(ICL,5) + KPR5
      IPR(ICL,6)=IPR(ICL,6) + KPR6
      IPR(ICL,7)=IPR(ICL,7) + KPR7
      RESID(ICL)=RESID(ICL) + R + RESV
      REWIND 21
      GO TO 19

  247 DD=(DL**2) + (DS**2)
      RX=.002727077*DD*ALEN
      RESID(ICL)=RESID(ICL) + RX + RESV
      REWIND 21
      GO TO 19

*******  SUMMARIZE STAND INFORMATION AND OUTPUT STAND SUMMARY
*******  TO UNIT 22
  250 PLOT=FLOAT(NPLOT)
      DO 260 I=1,5
         RESID(I)=(RESID(I)*BLOW)/PLOT
        DO 255 J=1,7
           PR(I,J)=IPR(I,J)*(BLOW/PLOT)
           IPR(I,J)=NINT(PR(I,J))
           VALTOT(I)=VALTOT(I) + (IPR(I,J)*SPEC(J,6))
  255   CONTINUE
  260 CONTINUE

      WRITE(22,270) ISTAND
  270 FORMAT('1'//5X,'STAND ',1X,I2,6X,'NET PRODUCT POTENTIAL FROM TREES
     1 WITH DEFECT')
      WRITE(22,275)
  275 FORMAT(20X,'ON PER ACRE BASIS USING MAX VALUE ALTERNATIVE'/20X,'FO
     1R EACH PIECE'///)
      WRITE(22,280)
  280 FORMAT(13X,'13 FT',1X,'17 FT',1X,'21 FT',7X,'PANEL',2X,'BARN')
      WRITE(22,285)
  285 FORMAT(1X,'DBH',3X,'POSTS',3(1X,'RAILS'),1X,'PROPS',2(1X,'POLES'),
     14X,'VOL',5X,'VALUE'/)

      DO 290 I=1,5
      WRITE(22,287)I+2,(IPR(I,J),J=1,7),RESID(I),VALTOT(I)
  287 FORMAT(2X,I1,5X,7(I3,3X),F6.2,3X,F6.2/)
  290 CONTINUE

      GO TO 17
 1000 STOP
      END

      SUBROUTINE SCAN

C          THIS SUBROUTINE SCANS FOR PRODUCTS

      CHARACTER PRODUCT*3,PRO*3,PIECE*3

      DIMENSION SPEC(7,6),DIVL(2),DIVS(2),DIVLN(2),SDBH(10),NUM(7),
     1LASTPROD(20),NPROD(7),BEG(10)

      REAL LDBH(10),LEN(10),L

      COMMON SPEC,LDBH,SDBH,LEN,NPROD,IPROD,ICT,RES,AST,LASTPROD,
     1NUMPROD,LASTCT,NUM,ICL,BEG
      COMMON /BK1/PRODUCT,PIECE

      ICLL=ICL + 2
      J=IPROD
      IF(J.EQ.6 .AND. LEN(ICT).EQ.17.) GO TO 375

C CHECK IF LARGE DIAMETER WITHIN PRODUCT SPECS
  370 IF((LDBH(ICT).LE.SPEC(J,5)).AND.(LDBH(ICT).GE.SPEC(J,4)))
     1THEN

C CHECK LENGTH TO SEE IF PRODUCT FITS
       IF(LEN(ICT).GE.SPEC(J,1)) THEN

C IF LENGTH EQUALS PRODUCT LENGTH, MAKE SURE SMALL DIAM IS LARGER
C THAN MINIMUM SMALL DIAM
        IF(LEN(ICT).EQ.SPEC(J,1)) THEN
          IF(SDBH(ICT).LT.SPEC(J,2)) GO TO 425
        ENDIF

C CALCULATE SMALL DIAM AT PRODUCT LENGTH
          D1=ICLL - ((SPEC(J,1)+BEG(ICT))*AST)
          IF(D1.LT.SDBH(ICT)) D1=SDBH(ICT)

C CHECK TO SEE IF SMALL DIAM WITHIN PRODUCT SPECS
          IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN

C TAKE PRODUCT OUT OF PIECE
             LDBH(ICT+1)=D1
             SDBH(ICT+1)=SDBH(ICT)
             LEN(ICT+1)=LEN(ICT)-SPEC(J,1)
             R1=(D1**2) + (SDBH(ICT)**2)
             RES=.002727077*R1*LEN(ICT+1)
             BEG(ICT+1)=BEG(ICT) + SPEC(J,1)
             NPROD(J)=NPROD(J) + 1
             LASTPROD(ICT)=J
             ICT=ICT+1
             PRODUCT='YES'
             GO TO 600
           ELSE

C IF SMALL DIAM STILL TOO BIG, TAKE AWAY 1 FOOT AND TRY AGAIN
```

```
             IF(D1.GT.SPEC(J,3)) THEN
                LDBH(ICT)=LDBH(ICT)-AST
                LEN(ICT)=LEN(ICT)-1.0
                GO TO 370
             ENDIF
           ENDIF
        ENDIF
      ELSE

C CHECK TO SEE IF PIECE NEEDS TO BE DIVIDED -- IF SMALL DIAM GREATER
C THAN MAX LARGE DIAM OF PRODUCT, NO PRODUCT CAN BE MADE FROM PIECE
        IF(SDBH(ICT).GT.SPEC(J,5)) GO TO 425

C CHECK TO SEE IF LARGE DIAM GREATER THAN MIN LARGE DIAM
        IF(LDBH(ICT).GT.SPEC(J,4)) THEN

C CHECK LENGTH TO SEE IF IT FITS
          IF(LEN(ICT).GE.SPEC(J,1)) THEN

C DETERMINE LENGTH AT MAX LARGE DIAM -- SPEC(J,5)
            L=(LDBH(ICT)-SPEC(J,5))/AST
            IF((LEN(ICT)-L).LT.SPEC(J,1)) GO TO 425

C DIVIDE THE PIECE
            DIVL(1)=LDBH(ICT)
            DIVS(1)=SPEC(J,5)
            DIVLN(1)=L
            DIVL(2)=SPEC(J,5)
            DIVS(2)=SDBH(ICT)
            DIVLN(2)=LEN(ICT)-L

C CHECK AGAIN TO SEE IF PRODUCT WILL FIT
  400       IF((DIVL(2).LE.SPEC(J,5)).AND.(DIVL(2).GE.SPEC(J,4))) THEN
               IF(DIVLN(2).GE.SPEC(J,1)) THEN
                 D1=DIVL(2)-(SPEC(J,1)*AST)
                 IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN
                   LDBH(ICT+1)=D1
                   SDBH(ICT+1)=SDBH(ICT)
                   LEN(ICT+1)=DIVLN(2)-SPEC(J,1)
                   R2=(D1**2) + (SDBH(ICT)**2)
                   RES=.002727077*R2*LEN(ICT+1)
                   NPROD(J)=NPROD(J) + 1
                   LASTPROD(ICT)=J
                   ICT=ICT+1
                   LASTCT=ICT
                   PRODUCT='YES'
                   GO TO 450
                 ELSE

C IF LARGE DIAM TOO BIG, TAKE AWAY 1 FOOT AND TRY AGAIN
                   IF(D1.GT.SPEC(J,3)) THEN
                     DIVLN(1)=DIVLN(1)+1
                     DIVLN(2)=DIVLN(2)-1
                     DIVL(2)=DIVL(2)-AST
                     DIVS(1)=DIVL(2)
                     GO TO 400
                   ENDIF
                 ENDIF
               ENDIF
             ENDIF
          ENDIF
        ENDIF
      ENDIF
  425 PRODUCT='NO'
      GO TO 600


******* CHECK FOR PRODUCT -- INITIALIZE THE NUMBER OF PRODUCTS
*******   TAKEN OUT OF PIECE

  450 J=1
      DO 460 K=1,NUMPROD
        NUM(K)=0
  460 CONTINUE
  475 IF((DIVL(1).LE.SPEC(J,5)).AND.(DIVL(1).GE.SPEC(J,4))) THEN
        IF(DIVLN(1).GE.SPEC(J,1)) THEN
          D1=DIVL(1)-(SPEC(J,1)*AST)
          IF((D1.GE.SPEC(J,2)).AND.(D1.LE.SPEC(J,3))) THEN

C TAKE PRODUCT OUT AND CHECK REMAINING PIECE FOR PRODUCTS

            R3=(D1**2) + (SDBH(ICT)**2)
            RES=.002727077*R3*DIVLN(1)
            PIECE='YES'
            DIVL(1)=D1
            DIVLN(1)=DIVLN(1)-SPEC(J,1)
            NPROD(J)=NPROD(J) + 1
            NUM(J)=NUM(J)+1
            GO TO 475
          ENDIF
        ENDIF
      ENDIF
      J=J+1
      IF(J.GT.NUMPROD) GO TO 600
      GO TO 475

C SPECIAL CASE FOR PANEL POLE WHEN LENGTH IS EXACTLY 17
  375 LDBH(ICT+1)=LDBH(ICT)
      SDBH(ICT+1)=SDBH(ICT)
      LEN(ICT+1)=0.0
      RES=0.0
      PRODUCT='YES'
      NPROD(J)=NPROD(J) + 1
      LASTPROD(ICT)=J
      ICT=ICT + 1

  600 RETURN
      END
```

```
********************************************
  NOTES ON DEFECT DATA FILE NEEDED IN ORDER
     TO RUN PROGRAM 3
********************************************

FOR EACH STAND
--------------
   FIRST LINE WILL HAVE : STAND NUMBER, NUMBER OF PLOTS,
         PLOT BLOW-UP FACTOR (2(I1,1X),F3.0)

   DATA LINES WILL HAVE : DBH CLASS, LARGE END DIAM, SMALL
         END DIAM, BEGINNING LENGTH, LENGTH OF PIECE, STEM
         TAPER, RESIDUAL VOLUME
        (I1,2(2X,F4.2),2(2X,F4.1),2X,F4.3,1X,F4.2)

   LAST LINE WILL HAVE : 9

LAST LINE OF DATA FILE WILL HAVE : 999

STEM TAPER
----------
   DBH CLASS 3 : 1/(MERCH LENGTH - 1)

   DBH CLASS 4 AND 5 : 2/(MERCH LENGTH - 1)

   DBH CLASS 6 AND 7 : 3/(MERCH LENGTH - 1)

LARGE AND SMALL END DIAMETERS
-----------------------------
   DL = DBH - (LENGTH FROM BUTT END)(TAPER)

   DS = DBH - (LENGTH FROM BUTT END)(TAPER)

RESIDUAL VOLUME
---------------
   COMPUTE THIS FOR THE DEFECTIVE PARTS OF EACH STEM
   USING THE FORMULA :

      V = (.002727077)(DL**2 + DS**2)(LENGTH)

EXAMPLE
-------
   5 INCH DBH CLASS WITH MERCHANTABLE LENGTH 30 FEET
     WHICH HAS CROOK FROM 0-2 AND FROM 27-30

          SCHEMATIC :

             5   DL                     DS    3
             /////_____________________///////
            0    2                     27     30


   TAPER = 2/29 = .069

   DL = 5 -(2*.069) = 4.86
   DS = 5 -(27*.069)= 3.14

   RESIDUAL VOL = .133 + .154 = .29
```

SAMPLE DATA FILE

```
2 7 100
3  2.75  2.00   3.0  10.0  .083  .09
3  2.60  2.33   6.0   4.0  .067  .37
3  2.90  2.00   2.5  22.5  .042  .07
3  2.89  2.00   2.0  17.0  .056  .05
3  3.00  2.31   1.0  15.5  .042  .22
4  3.00  2.00   9.0  10.0  .111  .55
4  3.76  2.00   3.0  23.0  .080  .16
4  3.85  2.00   2.0  25.0  .077  .08
4  3.80  2.00   2.5  23.5  .080  .12
4  3.89  2.00   1.5  27.5  .071  .04
5  4.86  3.14   2.0  25.0  .069  .29
5  4.48  3.00   5.5  16.5  .095  .55
5  5.00  3.94   1.0  16.0  .063 1.07
5  5.00  3.59   1.0  18.0  .074  .54
5  4.88  3.00   2.0  33.0  .059  .13
6  6.00  5.27   1.0   8.5  .077  .00
6  5.83  3.00   2.5  42.5  .068  .29
7  6.83  4.00   2.5  42.5  .068  .39
9
999
```

SAMPLE OUTPUT FOR ABOVE DATA FILE

```
    STAND    2        NET PRODUCT POTENTIAL FROM TREES WITH DEFECT
                      ON PER ACRE BASIS USING MAX VALUE ALTERNATIVE
                      FOR EACH PIECE


               13 FT 17 FT 21 FT       PANEL  BARN
DBH    POSTS RAILS RAILS RAILS PROPS POLES POLES     VOL        VALUE

 3         0     0     0     0    14    29     0    22.26      21.50

 4         0     0     0     0    43    43     0    22.92      43.00

 5        71    14    43     0     0     0     0    45.57      99.34

 6        57     0     0    14     0     0     0     8.00      49.94

 7        14     0    14     0     0     0    14     7.57      57.96
```

*U.S. GOVERNMENT PRINTING OFFICE: 1989-0-673-039/81009

Schlieter, Joyce A.; Hawkins, Charles H., III. 1989. Estimating commercial product potential in small-stem lodgepole pine: methods, products, values. Gen. Tech. Rep. INT-255. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 58 p.

Presents a procedure to assess commercial potential using conventional stand-table or cruise plot information. Includes a stem profile table, tables of alternative gross product mixes, gross/net product potential, as well as defect summaries for nine sample stands, and general computer routines.

KEYWORDS: forest management, wood products, timber management, timber harvesting

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**Intermountain
Research Station**

General Technical
Report INT-256

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Proceedings— Symposium on Shrub Ecophysiology and Biotechnology

UNIVER

SHRUB RESEARCH CONSORTIUM

USDA Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, Utah*, E. Durant McArthur (Chairman);

Brigham Young University, Provo, Utah* Jerran T. Flinders;

USDA Agricultural Research Service, Mountain States Area, Reno, Nevada*, James A. Young;

Utah State University, Logan, Utah*, Frederick D. Provenza;

State of Utah, Department of Natural Resources and Energy, Division of Wildlife Resources, Salt Lake City, Utah*, S. Dwight Bunnell;

University of California, Los Angeles, California, Evan M. Romney;

Colorado State University, Fort Collins, Colorado, William K. Lauenroth;

University of Idaho, Moscow, Idaho, Steven J. Brunsfeld;

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Oregon State University, Corvallis, Oregon, Lee E. Eddleman;

Eastern Oregon Agricultural Research Center, Burns, Oregon, Marshall R. Haferkamp;

New Mexico State University, Las Cruces, New Mexico, Max P. Dunford;

Texas A & M System, Texas Agricultural Experiment Station, San Angelo, Texas, Darrell N. Ueckert;

Texas Tech University, Lubbock, Texas, J. R. Goodin;

USDA Agricultural Research Service, High Plains Grassland Research Station, Cheyenne, Wyoming, D. Terrance Booth;

USDA Agricultural Research Service, Jornada Experimental Range, Las Cruces, New Mexico, Carlton H. Herbel;

University of Wyoming, Laramie, Wyoming, Rollin H. Abernethy.

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*Charter members

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Compilers:

ARTHUR WALLACE, Professor, Laboratory of Biomedical and Environmental Sciences, University of California-Los Angeles

E. DURANT McARTHUR, Supervisory Research Geneticist, Intermountain Research Station, Provo, UT

MARSHALL R. HAFERKAMP, Range Scientist, Agricultural Research Service, U.S. Department of Agriculture, Miles City, MT

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Forest Service
U.S. Department of Agriculture
324 25th Street
Ogden, UT 84401

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INTRODUCTION: SHRUB ECOPHYSIOLOGY AND BIOTECHNOLOGY

E. Durant McArthur, Arthur Wallace, and Marshall R. Haferkamp

This is the fifth in a series of symposium proceedings on the biology and management of shrubs. The first three were taxonomically oriented (Tiedemann and Johnson 1983; Tiedemann and others 1984; McArthur and Welch 1986); the fourth focused on animal relationships (Provenza and others 1987); and the fifth (this proceedings) has a physiological theme. The Shrub Research Consortium (see inside front cover of this proceedings) has sponsored these symposia as part of its role to facilitate the spread of knowledge of shrub biology and management. The Intermountain Research Station has published all five proceedings.

The presentations from this symposium are divided into three sections, Biotechnology and Breeding, Environmental Management and Technology, and Ecophysiology. The first section, Biotechnology and Breeding, examines some breeding system environmental response patterns of wildland shrubs (Pendleton and others; Sanderson and others), the tremendous potential for manipulation of plant species including wildland shrubs through the newly developing discipline of biotechnology (Carman), and application of some biotechnological techniques to one shrub, fourwing saltbush (Atriplex canescens) (Barrow; Wurtele). The second section, Environmental Management and Technology, examines vegetation establishment under a range of difficult conditions: Mohave Desert (both Romney and others papers), addition of polyacrylamide soil conditioners (Wallace and Wallace), and shrub community establishment in a northwestern riparian situation (Carson and Edgerton) and on reclaimed northeastern mine spoils (Hughes).

The third section, Ecophysiology, is the largest and most diverse. It includes papers covering a wide range of ecophysiological topics broadly divisible into water relations (Ansley and others; Booth; Carpenter and West; Ehleringer and Smedley; Sosebee and Wan), stress response and nutrition (Nelson and others; Nelson and Jolley, Rodriguez and Welch; Wallace, "Interaction..."), and processes (Meyer and Monsen; Noste and others; Stark; Wallace, "Comparative..."; Weber and others).

A few of the papers presented (Shrub Research Consortium 1987) are not included in this proceedings. Notable among these was the last professional paper presented by Dr. Raymond B. Farnsworth (1915-1987), Emeritus Professor of Agronomy and Horticulture at Brigham Young University who served 14 years as chairman of that department and 2 years as Acting Dean of the College of Biology and Agriculture. Dr. Farnsworth (photo) is remembered as a caring teacher and administrator. He was particularly concerned and involved with increasing agricultural productivity among less technologically advanced peoples, including native Americans. His symposium paper, "Some Unanswered Problems Concerning Nitrogen Fixation in Shrub Ecosystems," dealt with a longstanding research interest of his on nitrogen fixation by nonlegume, semi-arid adapted plants (Farnsworth and Hammond 1968; Farnsworth and others 1976; Farnsworth 1987).

Raymond B. Farnsworth

The symposium featured, in addition to the presented papers, a tour of laboratories of the Utah State University (USU) Biotechnology Center (Aust 1987) and a field tour to the Green Canyon field laboratory of the USU Ecology Center and the Intermountain Research Station Forestry Sciences Laboratory's plant physiology greenhouse. John Carman arranged and coordinated the biotechnology tour. The field tour was led by Martyn Caldwell and James Richards. It featured the ecophysiological (including grazing pressure) relationships of crested wheatgrass (Agropyron desertorum), bluebunch wheatgrass (A. spicatum), alfalfa (Medicago sativa), mountain big sagebrush (Artemisia tridentata ssp. vaseyana), forage kochia (Kochia prostrata), and fourwing saltbush (Atriplex canescens) (Caldwell and others 1981; Caldwell 1984, 1985; Richards

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E. Durant McArthur is Supervisory Research Geneticist, Intermountain Research Station, Forest Service, U. S. Department of Agriculture, Provo, UT; Arthur Wallace is Professor, Laboratory of Biomedical and Environmental Sciences, University of California-Los Angeles; Marshall R. Haferkamp is Range Scientist, Agricultural Research Service, U. S. Department of Agriculture, Miles City, MT (at the time of the symposium Dr. Haferkamp was stationed at Burns, OR).

and Caldwell 1985; Caldwell and Richards 1987; Pendery and Provenza 1987) and the drought tolerance of big sagebrush subspecies (Brown 1977; Welch and McArthur 1979; Brown and Collins 1980; McArthur 1983).

ACKNOWLEDGMENTS

We thank all members of the Shrub Research Consortium for their efforts in planning, publicizing, and conducting the symposium. In particular, we thank session discussion leaders D. Terrence Booth, Jerran T. Flinders, Marshall R. Haferkamp, and Fred D. Provenza. Kendall R. Johnson provided an instructive and delightful pair of slide-tape presentations at the banquet--"Moods of a Mountain" and the premier presentation of "Water on the Range." We also thank J. R. Goodin and Kevin R. Price for leading impromptu discussions on uses of biotechnology and remote sensing (Ridd and others 1984; Price 1987) in the resolution of shrub biology and management questions. We acknowledge others who helped with the symposium and its proceedings in various ways including Dee R. Funk and other staff of the USU Conference and Institute Division, Roberta L. Powell, and Nancy Clark.

REFERENCES

Aust, S. D. 1987. The biotechnology center. Utah Science. 48: 125-140.

Brown, R. W. 1977. Water relations of range plants. In: Sosebee, R. E., ed. Rangeland plant physiology. Denver, CO: Society for Range Management: 97-140.

Brown, R. W.; Collins, J. M. 1980. A screen-caged thermocouple psychrometer and calibration chamber for measurements of plant and soil water potential. Agronomy Journal. 72: 851-854.

Caldwell, M. M. 1984. Plant requirements for prudent grazing. In: National Academy of Sciences. Developing strategies for rangeland management. Boulder, CO: Westview Press: 117-152.

Caldwell, M. M. 1985. Competition between root systems in natural communities. In: Gregory, P. J.; Lake, J. V.; Rose, D. A., eds. Root development and function. New York, NY: Cambridge University Press: 167-185.

Caldwell, M. M.; Richards, J. H. 1987. Comparative ecophysiology of two bunchgrasses in competition with sagebrush. In: Abstracts, Fifth Wildland Shrub Symposium: shrub ecophysiology and biotechnology. Provo, UT: Shrub Research Consortium: 16.

Caldwell, M. M.; Richards, J. H.; Johnson, D. A.; Nowak, R. S.; Dzirec, R. S. 1981. Coping with herbivory: photosynthetic capacity and resource allocation in two semiarid Agropyron bunchgrasses. Oecologia. 50: 14-24.

Farnsworth, R. B. 1987. Some unanswered problems concerning nitrogen fixation in shrub ecosystems. In: Abstracts, Fifth Wildland Shrub Symposium: shrub ecophysiololgy and biotechnology. Provo, UT: Shrub Research Consortium: 13.

Farnsworth, R. B.; Hammond, M. W. 1968. Root nodules and isolation of endophyte on Artemisia ludoviciana. Proceedings of Utah Academy of Sciences, Arts, and Letters. 45: 182-188.

Farnsworth, R. B.; Romney, E. M.; and Wallace, A. 1976. Implications of symbiotic nitrogen fixation by desert plants. Great Basin Naturalist. 36: 65-80.

McArthur, E. D. 1983. Taxonomy, origin, and distribution of big sagebrush (Artemisia tridentata) and allies (subgenus Tridentatae). In: Johnson, K. L., ed. Proceedings of the first Utah Shrub Ecology Workshop; 1981 September 9-10; Ephraim, UT. Logan, UT: College of Natural Resources, Utah State University: 3-13.

McArthur, E. D.; Welch, B. L., compilers. 1986. Proceedings--Symposium on the biology of Artemisia and Chrysothamnus. Gen. Tech. Rep. INT-200; 1984 July 9-13; Provo, UT. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 398 p.

Pendery, B. M.; Provenza, F. D. 1987. Interplanting crested wheatgrass with shrubs and alfalfa: effects of competition and preferential clipping. Journal of Range Management. 40: 514-520.

Price, K. P. 1987. Detection of soil erosion with thematic mapper (TM) satellite data within pinyon-juniper woodlands. CRSC Rep. 87-2. Salt Lake City, UT: Center for Remote Sensing and Cartography, University of Utah Research Institute. 144 p.

Provenza, F. D.; Flinders, J. T.; McArthur, E. D., compilers. 1987. Proceedings--Symposium on plant-herbivore interactions. Gen. Tech. Rep. INT-222; 1985 August 7-9; Snowbird, UT. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 179 p.

Richards, J. H.; Caldwell, M. M. 1985. Soluble carbohydrates, concurrent photosynthesis and efficiency in regrowth following defoliation: a field study with Agropyron species. Journal of Applied Ecology. 22: 907-920.

Ridd, M. K.; Price, K. P.; Douglas, G. E. 1984. Assessment of lands at for rangeland mapping, Rush Valley, Utah. CRSC Rep. 84-9. Salt Lake City, UT: Center for Remote Sensing and Cartography, University of Utah Research Institute. 27 p.

Shrub Research Consortium. 1987. Abstracts, Fifth Wildland Shrub Symposium: shrub ecophysiology and biotechnology. Provo, UT: Shrub Research Consortium. 16 p.

Tiedemann, A. R.; Johnson, K. L., compilers. 1983. Proceedings--research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152; Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 279 p.

Tiedemann, A. R.; McArthur, E. D.; Stutz, H. C.; Stevens, R.; Johnson, K. L. compilers. 1984. Proceedings--symposium on the biology of Atriplex and related chenopods; 1983 May 2-6; Provo, UT. Gen. Tech. Rep. INT-172; Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 309 p.

Welch, B. L.; McArthur, E. D. 1979. Feasibility of improving big sagebrush (Artemisia tridentata) for use on mule deer winter ranges. In: Goodin, J. R.; Northington, D. K., eds. Arid land plant resources. Lubbock, TX: International Center for Arid and Semi-arid Land Studies, Texas Tech University: 451-473.

Section 1—Biotechnology and Breeding

BREEDING SYSTEMS OF WOODY PLANT SPECIES IN UTAH

Rosemary L. Pendleton, Burton K. Pendleton, and Kimball T. Harper

ABSTRACT: Breeding systems of all woody plant taxa listed in A Utah Flora were examined. A total of 351 species in 45 families were scored for floral, fruit, and growth characteristics, as well as ecological occurrence. A multivariate screening procedure was used to determine which variables best discriminate between monoecious, dioecious, polygamous, and perfect sexual systems. Pollen vector had the greatest influence, followed by woodiness and geographic occurrence for wind-pollinated species, and by height and flower color for animal-pollinated species. Factors affecting the evolution of these four sexual systems are discussed. Niche breadth was greater for dominant, wind-pollinated species and for wind- or bird-dispersed fruits. Optimal distance for gene flow apparently differs between ecological generalists and specialists.

INTRODUCTION

Plants exhibit an immense diversity of reproductive systems, ranging from completely selfing to obligate outcrossing, from bisexual flowers to unisexual individuals, and from monomorphic to trimorphic populations. Factors leading to the evolution of this diverse array have intrigued botanists since the mid-19th century (see Baker 1983). Historically, interest focused on the cataloguing of pollinators, arrangement of floral parts, and identification of pollination syndromes (Wyatt 1983). These syndromes refer to suites of morphological characters associated with definite pollen vectors such as wasp, hummingbird, moth, wind and others (Baker and Hurd 1968; Faegri and van der Pijl 1979; Proctor and Yeo 1973). Recently, the field of plant reproductive biology has experienced a resurgence of interest. The merging of traditional pollination biology with modern populations genetics has produced an experimentally based approach to breeding system evolution that currently receives much attention (Wyatt 1983).

Handel (1985) suggested three main components of plant breeding systems: 1) genetic recombination, including linkage and crossover, 2) pollination system, including pollen vector, outcrossing rate and arrangement of floral parts, and 3) dispersal of seeds. These three components set up patterns of gene flow within and between populations that are further modified by plant size (Dudash 1986; Handel 1985; Samson and Werk 1986), age (Floyd 1983; Lacey 1987), density (Handel 1983), and architecture (Webb and Lloyd 1986; Willson and Rathke 1974).

The optimal pattern of gene flow is dependent upon both biotic and abiotic components of the environment. Consequently, plant breeding systems must be viewed in an ecological context to be fully understood. Correlations between habitat and breeding system characteristics allow the identification of putative selective forces governing breeding system evolution. Several such correlation studies have previously been reported (Baker 1959; Bawa 1980; Collins 1983; Collins and others 1983; Fox 1985; Freeman and others 1980; Givnish 1980, 1982; Harper 1979; Muenchow 1987; Ostler and Harper 1978). Once identified, the role of putative factors can be examined critically through manipulative experimentation.

In this paper, we used plant morphology and habitat characteristics of the woody flora of Utah to examine broad trends in the ecological occurrence of reproductive systems and to compare our findings with those reported from other floras. We restrict the study to characteristics concerned with floral display, pollen vector, and seed dispersal. Information on outcrossing rates and genetic recombination is lacking for most of our native species. Specific questions addressed in this study are:

1. How does floral biology relate to plant morphology and ecology?
2. What ecological and morphological variables best discriminate between pollination systems?
3. Does relative abundance affect pollination system success?
4. Are ecological dominants more likely to be wind pollinated?
5. Is niche breadth greater for wind-pollinated species?
6. How is seed size related to means of dispersal?
7. Are pollen and seed dispersal mechanisms related?

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Rosemary L. Pendleton is Ecologist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT; Burton K. Pendleton is Ph.D. Candidate, Department of Biological Sciences, Wayne State University, Detroit, MI; Kimball T. Harper is Professor of Botany, Brigham Young University, Provo, UT.

METHODS

We surveyed all native woody plant species listed in Welsh and others' (1987) A Utah Flora. Plants were considered woody if described as suffruticose, shrubby, or arboreus. Cacti and other succulents were also included. Suffrutescent species were not included in the study. A total of 351 species in 45 families were scored for the following 12 morphological and ecological characteristics:

1. Woodiness (succulent, subshrub, shrub, small tree, tree, vine).
2. Height class (0.25 m, 0.25-2.0 m, 2.0-8.0 m, 8.0 m).
3. Sexual system (monoecious, dioecious, polygamo-monoecious, polygamo-dioecious, perfect).
4. Pollen vector (wind, animal).
5. Fruit succulence (fleshy, dry).
6. Fruit dispersal type (megawind, bird, mammal, sticktight, dehiscent capsule, no apparent means).
7. Seed diameter class (1 mm, 2-3 mm, 4-5 mm, 6-8 mm, 9-12 mm, 13 mm).
8. Geographic occurrence (dominant, common, uncommon).
9. Canopy layer (overstory, understory, open).
10. Elevational range (100-m increments).
11. Number of counties in which species occurs.
12. Niche width (total of scores 10 and 11).

Animal-pollinated species were scored for the following additional characteristics:

13. Flower access (restricted, semi-restricted, unrestricted).
14. Flower color (green, white, yellow, pink, red, purple, blue, brown, black).
15. Flower symmetry (radial, bilateral).

Red spectrum (pink, red, orange) and blue spectrum (blue, purple) colors were each combined for statistical analysis. Polygamo-monoecious and polygamo-dioecious were similarly combined. Restricted flowers are defined as having a floral tube 3 mm in length and a throat opening of 1 cm. Semi-restricted flowers have a floral tube 3 mm or a throat 1 cm. Open (unrestricted) flowers lack a floral tube and allow free access to pollen and nectar. Classification of fruit dispersal type was based primarily on fruit morphology. References in the literature were also reviewed and incorporated.

Welsh and others (1987) was used as the primary source of information. Other sources included Arnow and others (1980) Flora of the Central Wasatch Front, Utah, Munz (1968) A California Flora, Kearney and Peebles (1960) Arizona Flora, McMinn (1951) An Illustrated Manual of California Shrubs, and pressed specimens from the Brigham Young University herbarium (BRY). Geographic occurrence and canopy layer were scored subjectively by the authors. A complete listing of woody plant species and their scored characteristics is given in the Appendix.

Statistical Analysis

Preliminary analyses consisting of two-way contingency tables for sexual system against woodiness, height, pollen vector, fruit succulence, geographic occurrence, and canopy layer were carried out using the statistical package SPSS^{x} (SPSS Inc. 1983). This allowed us to compare our data with several other published studies, as well as to identify major trends. However, there are two major problems associated with this technique. First, observed correlations between two variables may actually be caused by their relationship to a third variable. For example, height, woodiness, and canopy layer are all highly intercorrelated. Second, although all have significant relationships, some variables may be more important (contain more information) than others. The use of multidimensional contingency tables circumvents the above two problems, but is sensitive with regard to empty cells and low expected values.

To determine which variables best discriminate between pollination systems, we used analysis of variance in a screening procedure somewhat analogous to backward stepwise regression. This procedure is one developed by Dr. Del T. Scott, Professor of Statistics, Brigham Young University, and is essentially a multivariate extension of the process described by Landis and Koch (1977). Use of this method allowed us to identify factors that remained significant while taking into account (controlling for) the other independent variables.

In the analysis, each sexual system (dioecious, monoecious, perfect, and polygamous) was treated as a separate dependent variable with levels of 1 and 0 for presence and absence, respectively. Woodiness, height, pollen vector, fruit succulence, geographic occurrence, canopy layer, flower color, symmetry, and access were all used as independent variables. A multivariate analysis of variance (General Linear Model) was carried out using the statistical package RUMMAGE available at Brigham Young University. Initially, all possible main effects and two-way interactions were examined. A completely saturated model, using higher order interactions, was not possible because of insufficient degrees of freedom. Following the initial run, variables and interactions with p values greater than 0.25 were omitted and the reduced model reanalyzed. This process was repeated until all factors left in the model were significant at or near the 0.05 level. Variables selected by the final model were examined more closely in chi-square contingency tables to determine trends with regard to pollination system.

The use of categorial data in an analysis designed for continuous variables requires some clarification. First, because the data are bivariate rather than continuous, small sample sizes may produce erratic results. Second, because the data represent the presence or absence of a particular trait, estimated values for group means become the percentage of total species expressing that trait or combination of traits. Where empty cells exist, the program calculates pseudovalues that are used in estimating the group or cell mean. Results based upon pseudovalues must be viewed with caution.

Other analyses were carried out using the packages SPSS^x (SPSS Inc. 1983). SAS (SAS Institute Inc. 1982), or standard statistical procedures (Zar 1984). Data dealing with the effects of wind pollination, seed size, commonness, and dominance were examined by means of chi-square contingency tables. A General Linear Models (GLM) analysis of variance was run on niche breadth using pollen vector as the classification variable. The niche breadth variable was obtained by summing the elevational range and the number of counties in which the species occurred. Since the two variables had approximately the same spread, a straight rather than weighted sum was used. The resultant variable was then log transformed (Zar 1984) to normalize the data.

Where possible, statistical analyses were carried out at both the genus and species levels. Analysis at the species level allowed the retention of critical variation most closely associated with specific habitats. Analyses at the genus level minimized problems imposed by phylogenetic constraints, that is, retained characteristics due to recent shared ancestry. Domination of distribution patterns by a few speciose taxa can lead to the formation of false conclusions (Muenchow 1987). The database for genus-level analysis was obtained by selecting the first species listed alphabetically within each genus. For the most part, results reported in this paper will be from species-level analyses. Genus-level results will be reported only when they differ significantly from species-level results.

RESULTS

Sexual Systems

At the species level, dioecy was positively associated with a shrub or tree life form, increasing height, common geographic occurrence, and an overstory habit (table 1). Monoecy was associated with small (8 m) and large trees, increasing height, dry fruit, dominance, and an overstory habit. Polygamous species were associated with subshrubs, small stature, uncommon occurrence, and open habitat. Perfect-flowered species were associated with either succulents or shrubs, small stature, fleshy fruits, uncommon occurrence, and either open or understory habits. Identical relationships were found at the genus level with the exception of the fruit succulence variable. At the genus level, dioecy was correlated with fleshy fruits ($X^2 = 8.322$, $p = 0.040$) while perfect-flowered species showed no visible pattern.

Initial results from the screening procedure identified pollen vector as the single most important variable for describing sexual system. Wind pollination was associated with the dioecious or monoecious state; animal pollination was associated with perfect flowers ($X^2 = 144.73$, p 0.0001). Similar results have been reported elsewhere (Freeman and others 1980; Givnish 1982; Muenchow 1987). Polygamy showed no bias toward either pollination system. Many of the trends reported in table 1 may be due to the association between sexual system and pollen vector. Trends reported for monoecy and dioecy were identical to those reported for wind pollination (table 2). Because of the great effect pollination vector has on sexual system, it seemed likely that other variables for discriminating between sexual

Table 1--Results from contingency table analyses for the association of sexual system with each of the variables listed below

	Woodiness	Height	Fruit[1] succulence	Geographic occurrence	Canopy layer
Dioecious	Shrub, large tree	Tall	No trend	Common	Overstory
Monoecious	Small and large trees	Tall	Dry	Dominant	Overstory
Polygamous	Subshrub	Short	No trend	Uncommon	Open
Perfect	Succulent, shrub	Short	Fleshy	Uncommon	Open, understory
P value	NA[2]	NA	0.0062	0.0000	0.0000

[1] Results differed at the genus level.

[2] Chi-square statistics not applicable because of low expected values and empty cells.

Table 2--Results from contingency table analyses for the association of sexual system with each of the variables listed below

	Woodiness	Height	Fruit[1] succulence	Geographic occurrence	Canopy layer
Wind	Small and large trees	Large stature	Dry	Dominant common	Overstory
Animal	Succulent, subshrub	Small stature	Fleshy	Uncommon	Open, understory
P value	0.0000	0.0000	0.0135	0.0000	0.0000

[1] Results were nonsignificant at the genus level.

systems might differ between vector groups. In subsequent analyses, wind- and animal-pollinated species were run separately.

Wind pollination--The final model for wind-pollinated species contained the variables woodiness, geographic occurrence, and their interaction (p = 0.000, 0.000, and 0.048, respectively). This model best explained the overall (multivariate) difference between sexual systems. On a univariate basis, the model was most useful for describing monoecious and polygamous species (see adjusted R^2 values from table 3). Correlations between these two sexual systems and both the woodiness and geographic occurrence variables were observed. Dioecy was also somewhat correlated with the woodiness variable. No significant association between perfect-flowered species and the above variables was found.

The interaction term was significant only for polygamous species. When we graphed this interaction (fig. 1), we found that a high proportion of polygamous species occurred only at the subshrub and vine levels of woodiness. Lines drawn between these two levels would be parallel.

Table 3--Univariate results from analysis of variance screening procedure for wind-pollinated species. W = woodiness; G = geographic occurrence; WG = interaction term

	Adjusted R^2	P values		
		W	G	WG
Dioecious	0.074	0.056	0.147	0.576
Monoecious	0.252	0.002	0.052	0.982
Polygamous	0.423	0.000	0.000	0.000
Perfect	0.010	0.278	0.315	0.614

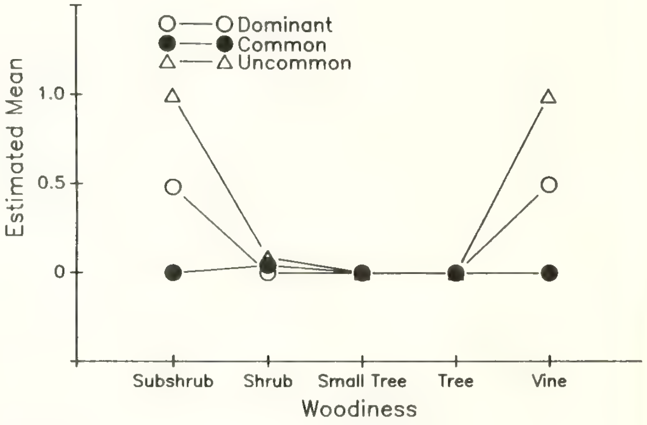

Figure 1--Estimated means from the woodiness-geographic occurrence interaction term for polygamous species.

The interaction term appears merely to reflect the lack of polygamous species at other levels of woodiness rather than any true interaction between the variables.

With the interaction term omitted, the effects of woodiness and geographic occurrence on sexual system could be examined directly through two-way contingency tables (tables 4, 5). Univariate statistics from the analysis of variance procedure were used to determine the significance of these relationships for each sexual system. Chi-square statistics were often of questionable value because of low expected values. The woodiness variable was significant for monoecy and polygamy, and nearly significant for dioecy (table 3). Monoecy was associated with small and large trees, while polygamy was overrepresented in the subshrubs (table 4). Dioecy appeared to be associated with the shrub habit. There was no pattern for perfect-flowered species. For geographic occurrence, monoecy occurred most often in dominant species, and polygamy in uncommon species (table 5). Dioecious and perfect-flowered species showed no significant trend.

Table 4--The relationship between woodiness and sexual system for wind-pollinated plant species (n = 88). The number of species exhibiting each combination of traits is listed above. Expected values are given in parentheses below

	Subshrub	Shrub	Small tree	Tree	Vine
Dioecious	- (1.13)	25 (19.88)	- (4.13)	7 (7.13)	1 (.075)
Monoecious	- (1.09)	11 (19.27)	9 (4.0)	12 (6.91)	- (0.73)
Polygamous	2 (0.20)	3 (3.61)	- (0.75)	- (1.30)	1 (0.14)
Perfect	1 (0.58)	14 (10.24)	2 (2.13)	- (3.67)	- (0.39)

Table 5--The relationship between geographic occurrence and sexual system for wind-pollinated plant species (n = 88). The number of species exhibiting each combination of traits is listed above. Expected values are given in parentheses below

	Geographic occurrence		
	Dominant	Common	Uncommon
Dioecious	4 (6.75)	17 (13.88)	12 (12.38)
Monoecious	13 (6.55)	10 (13.45)	9 (12.0)
Polygamous	- (1.23)	1 (2.52)	5 (2.25)
Perfect	1 (3.48)	9 (7.15)	7 (6.38)

At the genus level, woodiness and geographic occurrence were again the variables retained in the final model (p = 0.006 and 0.041, respectively). Univariate relationships were significant at the 0.10 level for monoecy and polygamy versus woodiness (p = 0.038 and 0.001, respectively) and for dioecy, monoecy, and polygamy versus geographic occurrence (p = 0.093, 0.016, and 0.094, respectively). Contingency tables show that monoecy was associated with both small and large tree life forms. Polygamy occurred only among subshrub or vine species. For geographic occurrence, dioecy occurred most often in common species, monoecy in dominant, and polygamy in uncommon species. Perfect-flowered species showed no significant trends.

Animal Pollination--The final model for animal-pollinated species contained the variables height, canopy layer, flower color, and the color-canopy interaction term (p = 0.017, 0.000, 0.000, and 0.000, respectively). Univariate results are given in table 6. This model best described dioecious and perfect-flowered species, as shown by the adjusted R-squared values. The significance of the monoecious terms is suspect because only four monoecious animal-pollinated species were included in the study. Results based on such a small sample size are of limited value, particularly when those results are expressed as percentages or proportions. The canopy layer and canopy-color interaction terms were significant only for monoecious species and can probably be eliminated from the model. Likewise, the significance of flower color in monoecious species will not be addressed.

We can now examine the effect of height and flower color on each sexual system. The variable height was significant only for dioecious species. The incidence of dioecy increased with height, going from 5.6 and 5.3 percent of the total species in categories 1 and 2 to 36.4 percent for category 3 and 100 percent of the total species in category 4. Floral color was significant for the dioecious and perfect floral systems. Dioecious species were predominantly green, or of the brown-black combination (table 7). Perfect-flowered species were mirror images, being underrepresented in the green, brown, or black colors and slightly overrepresented in the white or red-spectrum colors.

At the genus level, only the variable for flower color was retained in the final model. This variable was significant for dioecious and perfect species, and showed the same trend as that reported for the species level.

Niche Breadth and Geographic Occurrence

The following analyses dealt with questions of dominance and commonness, and their relation to means of pollen dispersal and sexual system. The preliminary contingency table analysis showed that dominant species were more likely to be pollinated by wind (table 2). This could be due

Table 6--Univariate results from analysis of variance screening procedure for animal-pollinated species

	Adjusted R^2	P values			
		Height	Canopy	Color	Color-canopy
Dioecious	0.627	0.001	0.217	0.000	0.417
Monoecious	0.199	0.832	0.000	0.000	0.000
Polygamous	0.000	0.368	0.532	0.416	0.722
Perfect	0.360	0.368	0.936	0.000	0.596

to a correlation between dominance and canopy layer. Dominant species were more likely to be found in the overstory (X^2 = 41.1, p 0.001), and overstory species were often wind-pollinated and monoecious (see tables 2 and 4). To control for a possible canopy layer effect, we examined the relationship of pollen vector to dominance within each canopy layer. Dominant species were still more likely to be wind-pollinated in open habitat (X^2 = 10.70, 0.001 p 0.005), though not in the understory (X^2 = 1.47, p = 0.48). Uncommon taxa were more likely to be pollinated by animals (X^2 = 30.23, p 0.001). They also tended to be perfect or polygamous (X^2 = 27.33, p 0.001). This was true even when the effect of pollen vector was taken into account. No differences were found between common and uncommon species for flower symmetry, access, or color.

Breadth of ecological adaptation was further examined using the niche width variable. Niche breadth was wider in wind-pollinated species at both the species (p = 0.0156) and genus (p = 0.027) levels.

Seed Dispersal Mechanisms

Seed size correlated strongly with dispersal mechanism (X^2 = 67.09, p 0.001). Although wind was important in every seed class category, seeds of 1 mm or less were almost exclusively dispersed by wind (table 8). Dehiscent capsules and sticktights were overrepresented in the 1-2 mm group. Fleshy fruits (generally bird dispersed) were overrepresented in the 3-5 mm group. Seeds greater than 6 mm were primarily mammal dispersed. Identical trends were observed at the genus level.

We also examined niche breadth as a function of seed dispersal system. Significant differences occurred between dispersal types at both genus (p = 0.046) and species (p = 0.018) levels. Bird and megawind dispersal types had the highest values for niche width. Mammal and sticktight dispersal types had the smallest.

Biotic and abiotic seed dispersal systems were compared with biotic and abiotic pollen

Table 7--The relationship between flower color and sexual system for animal-pollinated species. The number of species exhibiting each combination of traits is listed above. Expected values are given in parentheses below

	Flower color					
	Green	White	Yellow	Red	Blue	Brown/black
Dioecious	7 (1.3)	5 (10.6)	3 (9.0)	0 (3.3)	0 (2.3)	13 (1.4)
Monoecious	1 (0.2)	1 (1.5)	2 (1.3)	0 (0.5)	0 (0.3)	0 (0.2)
Polygamous	1 (0.7)	4 (5.7)	8 (4.8)	0 (1.8)	2 (1.3)	0 (0.7)
Perfect	3 (9.9)	90 (82.1)	72 (69.8)	31 (25.5)	20 (18.1)	1 (10.7)

Table 8--The relationship between seed size class and dispersal type. The number of species exhibiting each combination of traits is listed above. Expected values are given in parentheses below

	Seed size class (mm)			
	1	1-2	3-5	6
Wind	25	80	49	20
	(13.4)	(70.4)	(60.5)	(29.7)
Dehiscent capsule or sticktight	1	27	10	8
	(3.5)	(18.6)	(16.0)	(7.9)
Fleshy	0	25	35	8
	(5.2)	(27.5)	(23.6)	(11.6)
Animal	1	10	28	24
	(4.9)	(25.5)	(21.9)	(10.8)

Table 9--The relationship between abiotic or biotic pollen dispersal and seed dispersal. The number of species exhibiting each combination of traits is listed above. Expected values are given in parentheses below

	Pollen dispersal	
	Abiotic	Biotic
Seed Dispersal		
Abiotic		
Wind	62	112
	(43.6)	(130.4)
Dehiscent capsule	0	40
	(10.0)	(30.0)
Biotic		
Fleshy	10	58
	(17.0)	(51.0)
Sticktight	16	53
	(17.3)	(51.7)

dispersal. A chi-square test of the interdependence if pollen and seed dispersal systems was marginally significant ($X^2 = 4.44$, 0.025 p 0.05). When dispersal system was broken down into types, however, the test was highly significant ($X^2 = 27.734$, p 0.001) (see table 9).

DISCUSSION

The foregoing multivariate analyses were useful in determining which variables were most important in distinguishing sexual systems of plants. While other techniques for multidimensional analysis of categorical data exist, problems with empty cells and low expected values precluded their use. Variables retained in our study contained information above and beyond that due to correlation with other variables. For example, dioecy was related to height beyond what could be accounted for by canopy layer, woodiness, or pollen vector. It is important to emphasize that while trends with other variables exist, those retained in the model contain equivalent information.

The genus- and species-level analyses gave similar results in almost all cases. Lower levels of significance were attained due to the smaller database, but trends remained the same. The only real exception was the fruit fleshiness variable, which was significantly associated with dioecy at the genus level but not at the species level. the overall similarity between the two levels of analysis indicates that phylogenetic constraints are not a major consideration for this flora, at least at the genus-species taxonomic level.

The variable having the greatest effect on floral system is pollen vector. Forces affecting flower morphology and inflorescence architecture for the two systems are radically different. Animal-pollinated species must attract their pollinators by means of visual signals, odor, nectar, or pollen. Flower morphologies vary widely, but are generally showy and have a large, conspicuously colored perianth. In contrast, wind-pollinated species need neither attract nor reward their pollen vector. In anemophilous species, floral parts can inhibit pollen dispersal. Flowers of wind-pollinated plants tend to be unisexual, have a perianth that is greatly reduced or lacking, and produce copious amounts of pollen (Faegri and van der Pijl 1979). Wind-pollinated species tend to flower early in the growing season before large-scale animal pollination begins and, more importantly, before decidious species have leafed out. Leaves inhibit pollen flow (Whitehead 1983).

Wind pollination is a much less precise means of pollen transfer than animal-mediated pollination. Pollen transfer by wind is random within the context of prevailing winds. There is great potential for pollen wastage (Faegri and van der Pijl 1979; Richards 1986). Despite this drawback, wind pollination is important under certain environmental conditions and in certain geographic locations. On a large-scale basis, wind pollination increases with both elevation and latitude. It is uncommon in the tropics (Bawa 1980), but becomes the dominant means of pollination in northern deciduous and boreal forests (Whitehead 1969). Whitehead (1969) proposed a number of reasons for this pattern including the density and diversity of tropical floras, as well as existing weather patterns. Low temperature limits the activity of many animal pollinators, whereas rain greatly reduces the efficiency of wind pollination.

Wind pollination is common in the Intermountain region (Freeman and others 1980; McArthur, in press). Fully 25.1 percent of the woody plant species in Utah are pollinated by wind. Reasons for the high incidence of wind pollination in our region may be found by examining ecological correlates. Whitehead (1969, 1983) postulated conditions under which wind pollination will be effective. Wind pollination requires moderately dense vegetation of low diversity, or upper canopy status in more complex vegetation. A further requirement is the close spacing of compatible individuals. Since pollen transfer by wind has a large random component, the greater the proportion of compatible stigmas available in a given area, the more likely the chance of successful pollen transfer. Our results uphold Whitehead's ideas. We found wind pollination to be associated with tree life form, large stature, dry fruit, dominant or common occurrence, and an overstory canopy layer. Of these, life form (woodiness) and commonness of occurrence were the most efficient predictors of sexual system. Wind pollination was particularly associated with dominance. The Intermountain area is largely shrubland; large tracts of land are covered by low-growing dominants. Tree dominants reside as upper canopy species of more complex montane vegetation. These habitat conditions, coupled with the low level of rainfall, provide ideal situations for effective wind pollination.

Wind pollination has been implicated in the evolution of both monoecy and dioecy. We found wind pollination to be strongly correlated with these sexual systems. Nearly all monoecious plant taxa were pollinated by wind. Others have also found a correlation between wind and monoecy or dioecy in temperate zones (Freeman and others 1980; Muenchow 1987); a correlation not found in the tropics (Bawa 1980). The two primary reasons postulated for this correlation are the reduction of interference between male and female parts (Webb and Lloyd 1986) and a decrease in self-fertilization (Faegri and van der Pijl 1979). In wind-pollinated species, anthers and stigmas must be well-exposed to the wind in order for efficient pollination to occur. Separation of male and female parts likely enhances the dispersal of pollen. The separation of male and female parts into different flowers also reduces the amount of self pollen deposited on the stigma, increasing the opportunity for outcrossing. A substantial amount of self-fertilization can still occur, however, particularly as plant size increases. Wind-pollinated plants are often protogynous (Lloyd and Webb 1986), meaning stigmas are exerted before anthers on the same plant begin to dehisce. This greatly reduces the amount of self-fertilization. The separation of male and female parts into different individuals (dioecy) also overcomes this problem.

Freeman and his associates (1980) proposed a different reason for the correlation between wind pollination and dioecy. They proposed that dioecy evolved because of a differential success of male and female functions with microhabitat (see also Charnov 1982). Dioecy, in the region considered in their study, is associated with habitats where there is substantial patchiness in soil moisture. Female plants are overrepresented on more mesic sites. Wind pollination, they state, appears to have preceded the evolution of dioecy and may facilitate its development because of potentially uneven gene flow patterns set up by wind pollination in patchy or heterogeneous environments. Uneven patterns of gene flow have been used by others in explanations regarding the evolution of dioecy (see Bawa 1980). Freeman and his associates (1980) further proposed that dioecy is associated with woodiness because of the increased selfing that accompanies larger plant size, which allows a rapid spread of genes coding for dioecy. In this study, we did find a slight increase of dioecy with plant size, irrespective of pollination system.

Animal pollination is much more common than pollination by wind. In this study, we found animal pollination significantly overrepresented in taxa that were small in stature, of uncommon occurrence, and were found either in the open or understory. The more specific transfer of pollen made possible by animal vectors allows efficient pollination even in understory positions or where individuals are widely spaced. Animal-pollinated species generally have perfect flowers, though a substantial portion of dioecious species also exist in that category.

The evolution of these dioecious animal-pollinated species poses an especially intriguing problem to botanists. We found dioecious animal-pollinated species to be correlated with increasing height and with inconspicuous (green or brown) flower color. Other studies have found correlations between dioecy and woodiness, fleshy fruit, and inconspicuous flowers (Bawa 1980; Fox 1985; Givnish 1980, 1982; Muenchow 1987). Fleshy fruit has been proposed as a causal agent in the evolution of dioecious animal-pollinated species. Muenchow (1987) found a slight association between dioecy and fleshy fruit, even when woodiness and flower color were controlled for in the analysis. We found no such association. Although an association was found between dioecy and fleshy fruit at the genus level in the initial contingency table analysis, this association disappeared in the presence of other variables. In her study, Muenchow suggested that constraints on both pollination and dispersal in the shrubby understory accounted for the association. Only one dioecious animal-pollinated understory shrub was included in our study.

The association between dioecy and woodiness has been interpreted as an increased need for outcrossing in long-lived taxa (see references in Bawa 1980). We also found dioecy to be specifically associated with height. Again, this could reflect the increase in self-fertilization associated with increasing plant size. We could also apply the argument of Freeman and others (1980), reported earlier, that genes coding for dioecy could spread more rapidly under self-fertilization.

The strongest association observed for animal-pollinated dioecious species was flower color. Others have reported strong correlations with inconspicuous flowers or unspecialized pollinators, both in tropic and temperate species (Bawa 1980; Fox 1985; Muenchow 1987). Restricted foraging patterns of small, unspecialized pollinators result in little pollen movement between genotypes. The evolution of dioecy can increase pollen flow between individuals. An alternative explanation involving sexual selection has also been proposed (see Bawa 1980 for a more complete discussion).

Unlike other sexual systems, polygamy was not associated with either pollination vector. The incidence of polygamous species was associated with small stature, particularly subshrubs, and with uncommon occurrence. Very little is known about the evolution of polygamous species. It has been suggested as an intermediate between perfect-flowered species and monoecy or dioecy (B. Charlesworth and D. Charlesworth 1978; D. Charlesworth and B. Charlesworth 1978) and, as such, is considered an outcrossing mechanism (Bawa and Beach 1981). The associations reported above, which differ markedly from those of dioecious and monoecious species, suggest some other role.

Polygamo-monoecy may provide savings in the allocation of resources between male and female floral parts. Many perfect-flowered species produce more flowers than can mature into fruit (Stephenson 1981). One role proposed for these "extra" flowers is to act as functional males. Andro-monoecy (the production of perfect and male flowers by one individual) is functionally equivalent, yet provides savings in resources normally allocated to female floral parts. Gyno-monoecy (the production of perfect and female flowers by one individual) is fairly common in the Compositae. Resources saved through the reduction of male floral parts may be reallocated to petals to enhance attractiveness to pollinators (Bawa and Beach 1981; Richards 1986).

Widely distributed species generally have larger populations, more continuous distribution and a greater potential for gene flow than geographically restricted species. Small isolated populations with restricted gene flow are characteristic of endemics (Hamrick and others 1979; Loveless and Hamrick 1984). We found geographically common species to be associated with wind pollination. Wind pollination was also associated with greater niche width. Animal pollination was associated with uncommon occurrence and with narrow niche width. Harper (1979) also reported an overrepresentation of animal pollination in rare or endangered species. Wind can disperse pollen over long distances (Richards 1986), thus increasing effective population size and resulting in high levels of genetic variability in outcrossing species (Hamrick and others 1979; Loveless and Hamrick 1984). High levels of variability may benefit species that experience a wide variety of environmental conditions, both between and within populations. Narrow endemics, which experience less ecological variability, also exhibit lower levels of genetic variation (Hamrick and others 1979; Loveless and Hamrick 1984). Animal pollination (particularly bee pollination) results in more localized gene flow (Handel 1983; Richards 1986). In combination with small population size, this allows for a more structured population and fine-tuned genotypic adaptation (Waser and Price 1983).

Woodiness may play a part in the association between wind pollination, common occurrence, and increased genetic variability. Woody, long-lived perennials exhibit substantially more electrophoretic variation than herbaceous species (Hamrick and others 1979; Loveless and Hamrick 1984). Woody plants have slower maturation rates and so may have a slower rate of genetic fine-tuning to their environment. Also, taller species are subject to more extreme environmental conditions and may require a broader tolerance suppled through genetic heterogeneity.

Common or uncommon distribution patterns may be linked to floral morphology. Ostler and Harper (1978) found that locally uncommon species were more likely to have restricted access and zygmorphic flowers than were common species (see also Pendleton 1981). We found no difference between common and uncommon species with regard to floral access or symmetry. One reason for the differing results might be the different definitions for common and uncommon. We defined common on a geographic rather than a local basis. Common in a geographic sense is similar to niche width and reflects a broad adaptation. Common in a local sense reflects clumped spatial distribution. Harper (1979), however, did find geographically rare species to be associated with zygomorphic flower structure, though not with restricted access. Unlike Harper's study, our study focused on woody species only. Trends present in woody plant taxa sometimes differ from those present in the flora as a whole (Collins 1983; Ostler and Harper 1978).

Gene flow is also accomplished through the dispersal of seeds. A strong correlation was found between seed size and means of dispersal. This was not unexpected considering the different abilities of dispersal agents to transport mass. Van der Pijl (1982) reported a reduction in seed size for wind-dispersed fruits and commented on the ability of mammals to utilize large or heavy seeds. Dispersal agents that transport seeds farthest (birds, wind) were associated with greater niche width. Hamrick and his associates (1979) found greater, though nonsignificant, genetic variation in species dispersed by wind than in others. They did not differentiate bird-dispersed seeds. Wind is less efficient in dispersing seeds to specific habitats, but these species may have less specific habitat needs (see above). Dispersal by birds is more site-specific (Stiles 1987), yet birds are capable of transporting seeds for long distances. Birds and bird-dispersed fruits are more common in communities with complex vertical strata (Collins 1983). The correlation between bird-dispersed fruit and niche width may reflect, in part, the association between fleshy fruit and the tree life form. As mentioned previously, trees exhibit a large amount of genetic variation and are considered to be generalists in habitat requirements.

Van der Pijl (1982) cautioned that pollen and seed dispersal are separate phenomena and should be examined independently. Nevertheless, we found a significant relationship between means of pollen dispersal and means of seed dispersal. Species having wind-dispered seeds were also more likely to be pollinated by wind. Certainly, many of the constraints imposed on pollination by wind also apply to dispersal by wind. Wind dispersal should be most effective in open habitat or in canopy species or more complex vegetation. the capacity to exploit broad niches, as observed for dominant species, would also be compatible with the random nature of wind dispersal. Fleshy-fruited species were somewhat associated with animal pollination. Animal-pollinated species generally have a more restricted niche than wind-pollinated species. Birds are likely to disperse seeds to a habitat similar to that where they originated (Stiles 1987). Furthermore, understory species, which tend to be animal pollinated, are likely to be dispersed by wind. A clear exception to the overall correlation between pollination and dispersal was found in dehiscent capsules, which were exclusively animal pollinated. Capsules are multiple-seeded fruits and, as such, require animal pollination. Wind-pollinated species generally contain only one ovule per fruit (Faegri and van der Pijl 1979).

There are many other factors not mentioned here that affect plant breeding system. The degree of selfing versus outcrossing, incompatibility systems, and vegetative reproduction all affect gene flow. Also, temporal aspects of dispersal and flowering were not addressed.

Although a study of this kind cannot be inclusive, some implications for management can be drawn. Plants must be able to reproduce in place for long-term revegetation success. Species used for revegetation should be selected for their reproductive capabilities, as well as for vegetative growth characteristics. Wind-pollinated species should be planted as large continuous populations. Where wind pollination is predominate, species diversity should be kept low. Animal-pollinated species should be used in understory revegetation. Particular attention should be given to plants dependent on specialized animal pollinators to ensure that their pollination requirements are met. Several researchers have cautioned against the use of broad spectrum insecticides, particularly in areas of high species diversity or near populations of rare endemics (Harper 1979; Ostler 1976; Tepedino 1979).

REFERENCES

Arnow, L.; Albee, B.; Wyckoff, A. 1980. Flora of the Central Wasatch Front, Utah. Salt Lake City, Utah: University of Utah. 663 p.

Baker, H. G. 1983. An outline of the history of anthecology, or pollination biology. In: Real, L., ed. Pollination biology. Orlando, FL: Academic Press: 7-28.

Baker, H. G. 1959. Reproductive methods as factors in speciation in flowering plants. Cold Springs Harbor Symposium. Quantitative Biology. 24: 177-191.

Baker, H. G.; Hurd, P. D. 1968. Intrafloral ecology. Annual Review of Entomology. 13: 385-414.

Bawa, K. S. 1980. Evolution of dioecy in flowering plants. Annual Review of Ecology and Systematics. 11: 15-39.

Bawa, K. S.; Beach, J. H. 1981. Evolution of sexual systems in flowering plants. Annals of the Missouri Botanical Garden. 68: 254-274.

Charlesworth, B.; Charlesworth, D. 1978. A model for the evolution of dioecy and gynodioecy. American Naturalist. 112: 975-997.

Charlesworth, D.; Charlesworth, B. 1978. Population genetics of partial male-sterility and the evolution of monoecy and dioecy. Heredity. 41: 137-153.

Charnov, E. L. 1982. The theory of sex allocation. Princeton, NJ: Princeton University Press. 355 p.

Collins, P. D. 1983. Flower color, structure and fleshy fruited plants in an ecological context in northern Utah and adjacent areas. Provo, UT: Brigham Young University. 64 p. Dissertation.

Collins, P. D.; Harper, K. T.; Pendleton, B. K. 1983. Comparative life history and floral characteristics of desert and mountain floras in Utah. Great Basin Naturalist. 43: 385-393.

Dudash, M. R. 1986. The effect of plant size on male and female function in Sabatia angularis L. Gentianaceae, an obligately biennial, sand dune species. Abstract 174. American Journal of Botany. 74: 665.

Faegri, K.; van der Pijl, L. 1979. The principles of pollination ecology. New York: Pergamon Press. 244 p.

Floyd, M. E. 1983. Dioecy in five Pinus edulis populations in the Southwestern United States. American Midland Naturalist. 110: 405-411.

Fox, J. F. 1985. Incidence of dioecy in relation to growth form, pollination and dispersal. Oecologia. 67: 244-249.

Freeman, D. C.; Harper, K. T.; Ostler, W. K. 1980. Ecology of plant dioecy in the intermountain region of western North America and California. Oecologia. 44: 410-417.

Givnish, T. J. 1980. Ecological constraints in the evolution of breeding systems in seed plants: dioecy and dispersal in gymnosperms. Evolution. 34: 959-972.

Givnish, T. J. 1982. Outcrossing versus ecological constraints in the evolution of dioecy. American Naturalist. 118: 443-449.

Hamrick, J. L.; Linhart, Y. B.; Mitton, J. B. 1979. Relationships between life history characteristics and electrophoretically detectable genetic variation in plants. Annual Review of Ecology and Systematics. 10: 173-200.

Handel, S. N. 1983. Pollination ecology, plant population structure, and gene flow. In: Real, L., ed. Pollination biology. Orlando, FL: Academic Press: 163-211.

Handel, S. N. 1985. The intrusion of clonal growth patterns on plant breeding systems. American Naturalist. 125: 367-384.

Harper, K. T. 1979. Some reproductive and life history characteristics of rare plants and implication of management. In: The endangered species: a symposium. Great Basin Naturalist Memoirs. No. 3: 129-137.

Kearney, T. H.; Peebles, R. H. 1960. Arizona flora. Berkeley, CA: University of California Press. 1085 p.

Lacey, E. P. 1987. Onset of reproduction in plants: size- versus age-dependency. Trends in Ecology and Evolution. 1: 72-75.

Landis, J. R.; Koch, G. G. 1977. A one-way components of variance model for categorial data. Biometrics. 33: 671-679.

Lloyd, D. G.; Webb, C. J. 1986. The avoidance of interference between the presentation of pollen and stigmas in angiosperms I. Dichogany. New Zealand Journal of Botany. 24: 135-162.

Loveless, M. D.; Hamrick, J. L. 1984. Ecological determinants of genetic structure in plant populations. Annual Review of Ecology and Systematics. 15: 65-95.

McArthur, E. D. [In press]. Breeding systems in shrubs. In: McKell, C. M., ed. The biology and utilization of shrubs. San Diego, CA: Academic Press.

McMinn, H. E. 1951. An illustrated manual of California shrubs. Berkeley, CA: University of California Press. 663 p.

Muenchow, G. E. 1987. Is dioecy associated with fleshy fruit? American Journal of Botany. 74: 287-293.

Munz, P. A. 1968. A California flora. Berkeley, CA: University of California Press. 1681 p.

Ostler, W. K. 1976. Correlations between plant species diversity and flower characteristics in the Wasatch mountains of Utah and Idaho. Provo, UT: Brigham Young University. 52 p. Thesis.

Ostler, W. K.; Harper, K. T. 1978. Floral ecology in relation to plant species diversity in the Wasatch Mountains of Utah and Idaho. Ecology. 59: 848-861.

Pendleton, B. K. 1981. Aspects of the floral biology of a subalpine meadow of the Uinta Mountains, Utah. Provo, UT: Brigham Young University. 54 p. Thesis.

Proctor, M. C. F.; Yeo, P. F. 1973. The pollination of flowers. The New Naturalist Series. No. 54. London: Collins. 418 p.

Richards, A. J. 1986. Plant breeding systems. London: George Allen and Unwin. 529 p.

Samson, D. A.; Werk, K. S. 1986. Size-dependent effects in the analysis of reproductive effort in plants. American Naturalist. 127: 667-680.

SAS Institute Inc. 1982. SAS user's guide: statistics. Cary, NC: SAS Institute Inc. 584 p.

SPSS Inc. 1983. SPSS^x user's Guide. New York: McGraw-Hill Book Company. 806 p.

Stephenson, A. G. 1981. Flower and fruit abortion: proximate causes and ultimate functions. Annual Review of Ecology and Systematics. 12: 253-279.

Stiles, E. W. 1987. Seed dispersal timing and spatial heterogeneity in seed banks. Abstract 119. American Journal of Botany. 74: 638.

Tepedino, V. J. 1979. The importance of bees and other insect pollinators in maintaining floral species composition. In: The endangered species: a symposium. Great Basin Naturalist Memoirs. No. 3: 139-150.

van der Pijl, L. 1982. Principles of dispersal in higher plants. 3d ed. New York: Springer-Verlag. 215 p.

Waser, N. M., and M. V. Price. 1983. Optimal and actual outcrossing in plants, and the nature of plant-pollinator interaction. In: Jones, C. E.; Little, R. J., eds. Handbook of experimental pollination biology. New York: Scientific and Academic Editions: 341-359.

Webb, C. J.; Lloyd, D. G. 1986. The avoidance of interference between the presentation of pollen and stigmas in angiosperms II. Herkogamy. New Zealand Journal of Botany. 24: 163-178.

Welsh, S. L.; Atwood, N. D.; Higgins, L. C.; Goodrich, S. 1987. A Utah flora. Great Basin Naturalist Memoirs. No. 9. 894 p.

Whitehead, D. R. 1969. Wind pollination in the angiosperms: evolutionary and environmental considerations. Evolution. 23: 28-35.

Whitehead, D. R. 1983. Wind pollination: some ecological and evolutionary perspectives. In: Real, L., ed. Pollination biology. Orlando, FL: Academic Press: 97-108.

Willson, M. F.; Rathke, B. J. 1974. Adaptive design of the floral display in *Asclepias syriaca* L. American Midland Naturalist. 92: 47-57.

Wyatt, R. 1983. Pollinator-plant interactions and the evolution of breeding systems. In: Real, L., ed. Pollination biology. Orlando, FL: Academic Press: 51-95.

Zar, J. H. 1984. Biostatistical Analysis. 2d ed. Englewood Cliffs, NJ: Prentice-Hall, Inc. 718 p.

APPENDIX

Ecological and morphological characteristics of the woody plant species in Utah. Nomenclature follows Welsh and others' (1980) *A Utah Flora*. Characteristics are coded according to the following key: (1) Woodiness; Sc = succulent, SS = subshrub, S = shrub, ST = small tree, T = tree, V = vine, (2) height; 1 = 0.25 m, 2 = 0.25-2.0 m, 3 = 2.0-8.0 m, 4 = 8.0 m, (3) sexual system; M = monoecious, D = dioecious, Po = polygamo-monoecious, PoD = polygamo-dioecious, P = perfect, (4) pollen vector; W = wind pollinated, A = animal pollinated, (5) fruit succulence; FL = fleshy, D = dry, (6) fruit dispersal; Fl = bird, A = mammal, DC = dehiscent capsule, St = sticktight, W = microwind, MW = megawind, N = no apparent means, (7) seed diameter; 1 = 1 mm, 2 = 2-3 mm, 3 = 4-5 mm, 4 = 6-8 mm, 5 = 9-12 mm, 6 = 13 mm, (8) geographic occurrence; D = dominant, C = common, U = uncommon, (9) canopy layer; O = overstory, U = understory, X = open habitat, (10) elevational range in 100-m increments, (11) number of counties in which the species occurs, (12) niche width; the sum of characters 10 and 11, (13) flower access; R = restricted, S = semi-restricted, O = unrestricted. See Methods section for a definition of these terms, (14) flower color; G = green, W = white, Y = yellow, P = pink, R = red, Pu = purple, Bl = blue, B = brown or black, and (15) flower symmetry; R = radial, B = bilateral. the latter three characteristics were scored only for animal-pollinated species. Vines were not scored for height.

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GYMNOSPERMAE															
Cupressaceae															
Juniperus communis	S	2	D	W	Fl	Fl	3	U	U	19	26	45			
Juniperus osteosperma	ST	3	M	W	Fl	Fl	4	D	O	16	28	44			
Juniperus scopulorum	T	3	D	W	Fl	Fl	3	C	O	14	28	42			
Ephedraceae															
Ephedra fasciculata	S	2	D	W	D	A	4	U	X	4	1	5			
Ephedra nevadensis	S	2	D	W	D	A	4	C	X	14	13	27			
Ephedra torreyana	S	2	D	W	D	A	4	C	X	15	9	24			
Ephedra viridis	S	2	D	W	D	A	4	U	X	22	18	40			
Pinaceae															
Abies concolor	T	4	M	W	D	W(A)	5	D	O	17	26	43			
Abies lasiocarpa	T	4	M	W	D	W	4	D	O	10	26	36			
Picea engelmannii	T	4	M	W	D	W	3	D	O	11	28	39			
Picea pungens	T	4	M	W	D	W	2	C	O	12	19	31			
Pinus contorta	T	4	M	W	D	W	3	D	O	14	6	20			
Pinus edulis	T	4	M	W	D	A	5	D	O	16	19	35			
Pinus flexilis	T	4	M	W	D	A	5	U	O	18	27	45			
Pinus longaeva	T	4	M	W	D	W(A)	4	C	O	12	14	26			
Pinus monophylla	T	4	M	W	D	A	6	D	O	18	11	29			
Pinus ponderosa	T	4	M	W	D	W(A)	4	D	O	12	21	33			
Pseudotsuga menziesii	T	4	M	W	D	W	3	D	O	17	28	45			
ANGIOSPERMAE															
Agavaceae															
Agave utahensis	Sc	3	P	A	D	DC	3	U	X	7	1	8	R	Y	R
Nolina microcarpa	S	2	D	A	D	W	3	U	X	1	1	2	O	W	R
Yucca angustissima	Sc	2	P	A	D	DC	5	U	X	17	8	25	O	W	R
Yucca baccata	Sc	2	P	A	Fl	A	5	C	X	17	5	22	O	W	R
Yucca baileyi	Sc	2	P	A	D	DC	4	C	X	11	4	15	O	W	R
Yucca brevifolia	ST	2	P	A	Fl	A	4	C	X	15	1	16	O	W	R
Yucca harrimaniae	Sc	2	P	A	D	DC	5	C	X	16	14	30	O	Y	R
Yucca kanabensis	Sc	2	P	A	D	DC	5	C	X	11	2	13	O	W	R
Yucca schidigera	S	2	P	A	Fl	A	4	U	X	7	1	8	O	W	R
Yucca toftiae	Sc	2	P	A	D	DC	4	U	X	8	3	11	O	W	R
Yucca utahensis	Sc	2	P	A	D	DC	4	C	X	11	1	12	O	W	R

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aceraceae															
Acer glabrum	ST	3	M	A(W)	D	W	3	U	U	16	28	44	O	G	R
Acer grandidentatum	ST	3	M	W(A)	D	W	3	C	O	16	25	41			
Acer negundo	T	4	D	W	D	W	5	U	O	16	26	42			
Anacardiaceae															
Rhus glabra	ST	2	Po	A	Fl	Fl	3	U	X	13	10	23	O	G	R
Rhus aromatica	S	2	Po	A	Fl	Fl	3	C	O	16	26	42	O	Y	R
Toxicodendron rydbergii	S	1	D	A	Fl	Fl	3	U	O	13	17	30	O	W	R
Asteraceae															
Acamptopappus sphaerocephalus	S	2	P	A	D	W	2	C	X	6	3	9	S	Y	R
Ambrosia dumosa	S	2	M	W	D	ST	2	C	X	4	1	5			
Ambrosia eriocentra	S	2	M	W	D	ST	2	U	X	4	1	5			
Amphipappus fremontii	S	2	P	A	D	W	2	U	X	3	1	4	S	Y	R
Artemisia arbuscula	S	2	P	W	D	W	2	C	X	13	7	20			
Artemisia bigelovii	S	2	Po	W	D	W	2	U	X	12	10	22			
Artemisia cana	S	2	P	W	D	W	2	C	X	9	19	28			
Artemisia filifolia	S	2	M	W	D	W	1	C	X	16	8	24			
Artemisia frigida	S	1	P	W	D	W	2	U	X	27	21	48			
Artemisia longiloba	S	2	P	W	D	W	2	U	X	8	2	10			
Artemisia nova	S	1	P	W	D	W	2	C	X	13	22	35			
Artemisia pygmaea	S	1	P	W	D	W	2	U	X	8	12	20			
Artemisia spiciformis	S	2	P	W	D	W	2	U	X	5	10	15			
Artemisia spinescens	S	1	M	W	D	W	2	U	X	8	17	25			
Artemisia tridentata	S	2	P	W	D	W	2	C	X	20	28	48			
Artemisia tripartita	S	2	P	W	D	W	2	C	X	4	2	6			
Baccharis emoryi	S	2	D	W	D	MW	2	C	X	5	3	8			
Baccharis glutinosa	S	2	D	W	D	MW	2	C	X	5	2	7			
Baccharis salicina	S	2	D	W	D	MW	2	C	X	4	4	8			
Baccharis sergilloides	S	2	D	W	D	MW	2	U	X	2	1	3			
Baccharis viminea	S	3	D	W	D	MW	2	U	X	3	1	4			
Baccharis wrightii	S	2	D	W	D	MW	2	U	X	3	1	4			
Bebbia juncea	S	2	P	A	D	W	2	U	X	2	1	3	S	Y	R
Brickellia atractyloides	S	2	P	A	D	W	3	U	X	4	3	7	R	W	R
Brickellia californica	SS	2	P	A	D	W	3	U	X	14	11	25	S	W	R
Brickellia longifolia	S	2	P	A	D	W	2	U	X	9	7	16	S	W	R
Brickellia microphylla	S	2	P	A	D	W	3	U	X	16	15	31	S	W	R
Brickellia oblongifolia	SS	2	P	A	D	W	3	U	X	13	14	27	R	W	R
Chrysothamnus albidus	S	2	P	A	D	W	3	U	X	3	5	8	R	W	R
Chrysothamnus depressus	S	1	P	A	D	W	4	C	U	14	18	32	R	Y	R
Chrysothamnus greenei	S	2	P	A	D	W	3	C	X	15	13	28	S	Y	R
Chrysothamnus linifolius	S	2	P	A	D	W	2	U	X	15	12	27	S	Y	R
Chrysothamnus nauseosus	S	2	P	A	D	W	3	C	X	23	28	51	R	Y	R
Chrysothamnus paniculatus	S	2	P	A	D	W	2	C	X	6	1	7	R	Y	R
Chrysothamnus parryi	S	2	P	A	D	W	4	U	X	13	19	32	R	Y	R
Chrysothamnus pulchellus	S	2	P	A	D	W	3	U	X	11	3	14	R	Y	R
Chrysothamnus vaseyi	S	1	P	A	D	W	3	U	X	13	13	26	S	Y	R
Chrysothamnus viscidiflorus	S	2	P	A	D	W	3	C	U	20	28	48	S	Y	R
Dyssodia acerosa	SS	1	Po	A	D	W	3	U	X	4	3	7	R	Y	R
Dyssodia pentachaeta	SS	1	Po	A	D	W	2	U	X	6	1	7	S	Y	R
Encelia farinosa	S	2	P	A	D	W	3	U	X	1	1	2	S	Y	R
Encelia frutescens	S	2	P	A	D	W	4	U	X	11	5	16	S	Y	R
Gutierrezia microcephala	S	2	M	A	D	W	2	C	X	10	10	20	S	Y	R
Gutierrezia petradoria	SS	2	M	A	D	W	3	U	X	8	1	9	S	Y	R
Gutierrezia pomariensis	SS	2	Po	A	D	W	2	U	X	7	2	9	S	Y	R
Gutierrezia sarothrae	S	2	Po	A	D	W	2	C	X	17	28	45	S	Y	R
Haplopappus cervinus	S	2	P	A	D	W	2	U	X	8	2	10	S	Y	R
Haplopappus crispus	S	2	P	A	D	W	4	U	X	7	2	9	R	Y	R
Haplopappus drummondii	SS	2	P	A	D	W	2	U	X	8	5	13	S	Y	R
Haplopappus laricifolius	S	2	P	A	D	W	2	U	X	1	1	2	S	Y	R
Haplopappus linearifolius	S	2	P	A	D	W	3	U	X	8	1	9	R	Y	R
Haplopappus macronema	S	2	P	A	D	W	4	U	X	14	13	27	R	Y	R
Haplopappus nanus	S	1	P	A	D	W	3	U	X	16	7	23	S	Y	R

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Haplopappus scopulorum	S	2	P	A	D	W	3	U	U	5	4	9	S	Y	R
Haplopappus watsonii	S	2	P	A	D	W	3	U	X	22	10	32	S	Y	R
Haplopappus zionis	S	1	P	A	D	W	4	U	X	8	3	11	R	Y	R
Hofmeisteria pluriseta	S	2	P	W	D	W	2	U	X	4	1	5			
Hymenoclea salsola	S	2	M	W	D	W	3	U	X	3	1	4			
Lepidospartum latisquanum	S	2	P	A	D	W	2	U	X	1	1	2	S	Y	R
Parthenium incanum	S	2	M	A	D	W	2	U	X	1	1	2	S	W	R
Perityle specuicola	SS	2	P	A	D	W	3	U	X	2	2	4	S	W	R
Perityle stansburyi	SS	1	Po	A	D	W	3	U	X	7	8	15	S	Y	R
Perityle tenella	SS	1	P	A	D	W	3	U	X	13	1	14	S	Y	R
Peucephyllum schottii	S	2	P	A	D	W	3	U	X	1	1	2	S	Y	R
Pluchea sericea	S	2	Po	A	D	W	2	C	X	8	4	12	S	Pu	R
Psilostrophe cooperi	S	2	Po	A	D	W	4	U	X	13	1	14	S	Y	R
Sphaeromeria diversifolia	SS	2	Po	W	D	W	2	U	X	19	6	25			
Sphaeromeria ruthiae	SS	2	Po	W	D	W	2	U	X	8	1	9			
Tetradymia axillaris	S	2	P	A	D	W	3	U	X	6	1	7	R	Y	R
Tetradymia canescens	S	2	P	A	D	W	3	C	X	17	28	45	R	Y	R
Tetradymia glabrata	S	2	P	A	D	W	3	U	X	11	9	20	R	Y	R
Tetradymia nuttallii	S	2	P	A	D	W	3	U	X	5	9	14	R	Y	R
Tetradymia spinosa	S	2	P	A	D	W	4	U	X	7	15	22	R	Y	R
Vanclevea stylosa	S	2	P	A	D	W	3	C	X	6	6	12	R	Y	R
Xylorhiza cronquistii	SS	1	Po	A	D	W	3	U	X	3	1	4	R	W	R
Xylorhiza glabriuscula	SS	1	Po	A	D	W	3	U	X	7	3	10	S	W	R
Xylorhiza tortifolia	SS	2	Po	A	D	W	3	U	X	12	6	18	R	Bl	R
Berberidaceae															
Berberis fendleri	S	2	P	A	Fl	Fl	3	U	X	8	2	10	O	Y	R
Mahonia fremontii	S	2	P	A	Fl	Fl(W)	3	C	X	17	6	23	O	Y	R
Mahonia repens	S	1	P	A	Fl	Fl	3	C	U	20	28	48	O	Y	R
Betulaceae															
Alnus incana	ST	3	M	W	D	W	3	C	O	15	15	30			
Betula glandulosa	S	2	M	W	D	W	2	U	O	8	6	14			
Betula occidentalis	ST	3	M	W	D	W	2	C	O	16	28	44			
Ostrya knowltonii	ST	3	M	W	D	W	4	U	O	6	3	9			
Bignoniaceae															
Chilopsis linearis	ST	3	P	A	D	W	4	U	O	8	1	9	R	W	B
Brassicaceae															
Lepidium fremontii	SS	2	P	A	D	W	2	U	X	9	1	10	O	W	R
Buddlejaceae															
Buddleja utahensis	S	2	P	A	D	DC	2	U	X	4	1	5	S	Y	R
Cactaceae															
Coryphantha missouriensis	Sc	1	P	A	Fl	A	2	U	X	7	2	9	O	Y	R
Coryphantha vivipara	Sc	1	P	A	Fl	A	2	U	X	14	14	28	O	P	R
Echinocactus polysephalus	Sc	2	P	A	D	A	3	U	X	3	2	5	R	Y	R
Echinocereus engelmannii	Sc	1	P	A	Fl	Fl	2	U	X	12	7	19	O	P	R
Echinocereus triglochidiatus	Sc	1	P	A	Fl	Fl	2	U	X	17	20	37	S	R	R
Ferrocactus acanthodes	Sc	2	P	A	D	A	2	U	X	7	1	8	O	Y	R
Mammillaria tetrancistra	Sc	1	P	A	Fl	Fl	2	U	X	6	1	7	O	R	R
Neolloydia johnsonii	Sc	1	P	A	D	A	2	U	X	6	1	7	O	Pu	R
Opuntia acanthocarpa	S	2	P	A	D	A	4	U	X	5	1	6	O	R	R
Opuntia basilaris	Sc	1	P	A	D	A	4	U	X	11	5	16	O	Pu	R
Opuntia chlorotica	S	2	P	A	Fl	A	2	U	X	1	1	2	O	Y	R
Opuntia echinocarpa	S	2	P	A	D	A	2	U	X	7	2	9	O	Y	R
Opuntia erinacea	Sc	1	P	A	D	A	3	U	X	21	26	47	O	Y	R
Opuntia fragilis	Sc	1	P	A	D	A	4	U	X	13	15	28	O	Y	R
Opuntia littoralis	Sc	2	P	A	Fl	A	3	U	X	1	2	3	O	Y	R
Opuntia macrorhiza	Sc	1	P	A	Fl	A	3	U	X	12	7	19	O	Y	R
Opuntia nicholii	Sc	1	P	A	D	A	4	U	X	4	3	7	O	Pu	R
Opuntia phaeacantha	Sc	2	P	A	Fl	A	3	U	X	12	4	16	O	Y	R
Opuntia polyacantha	Sc	1	P	A	D	A	3	C	X	16	28	44	O	Y	R
Opuntia pulchella	Sc	1	P	A	Fl	A	3	U	X	5	4	9	O	Pu	R
Opuntia whipplei	Sc	2	P	A	Fl	A	3	U	X	7	7	14	O	Y	R
Pediocactus despainii	Sc	1	P	A	D	A	3	U	X	1	1	2	O	Y	R
Pediocactus sileri	Sc	1	P	A	D	A	3	U	X	8	2	10	O	Y	R
Pediocactus simpsonii	Sc	1	P	A	D	A	2	U	X	14	19	33	O	W	R

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pediocactus winkleri	Sc	1	P	A	D	A	3	U	X	2	1	3	O	P	R
Sclerocactus pubispinus	Sc	1	P	A	D	A	3	U	X	6	7	13	O	Y	R
Sclerocactus whipplei	Sc	2	P	A	D	A	2	U	X	14	10	24	O	P	R
Sclerocactus wrightiae	Sc	1	P	A	D	A	3	U	X	5	2	7	O	Y	R
Caprifoliaceae															
Linnaea borealis	SS	1	P	A	D	N	2	U	U	12	8	20	R	P	B
Lonicera involucrata	S	2	P	A	Fl	Fl	3	U	X	19	20	39	R	Y	B
Lonicera utahensis	S	2	P	A	Fl	Fl	3	U	U	17	12	29	R	Y	B
Sambucus caerulea	S	2	P	A	Fl	Fl	3	U	X	15	28	43	O	W	R
Sambucus racemosa	S	2	P	A	Fl	Fl	3	C	X	16	22	38	O	W	R
Symphoricarpos longiflorus	S	2	P	A	Fl	Fl	3	U	X	21	15	36	R	P	R
Symphoricarpos occidentalis	S	2	P	A	Fl	Fl	3	C	U	5	3	8	S	P	R
Symphoricarpos oreophilus	S	2	P	A	Fl	Fl	3	C	U	20	16	36	R	P	R
Caryophyllaceae															
Arenaria macradenia	SS	2	P	A	D	DC	2	U	X	22	11	33	O	W	R
Celastraceae															
Forsellesia meionandra	S	2	P	A	D	DC	3	U	X	9	9	18	O	W	R
Forsellesia nevadensis	S	2	P	A	D	DC	3	U	X	7	6	13	O	W	R
Mortonia scabrella	S	2	P	A	D	DC	3	U	X	5	1	6	O	W	R
Pachystima myrsinites	S	2	P	A	D	DC	3	C	U	16	28	44	O	R	R
Chenopodiaceae															
Allenrolfea occidentalis	S	2	P	W	D	W	1	C	X	3	15	18			
Atriplex canescens	S	2	D	W	D	W	2	C	X	18	23	41			
Atriplex confertifolia	S	2	D	W	D	W	2	D	X	13	25	38			
Atriplex corrugata	S	1	D	W	D	W	2	D	X	11	9	20			
Atriplex gardneri	S	2	D	W	D	W	2	D	X	10	20	30			
Atriplex garrettii	S	2	D	W	D	W	2	U	X	9	5	14			
Atriplex hymenelytra	S	2	D	W	D	W	2	U	X	1	1	2			
Atriplex lentiformis	S	2	D	W	D	W	2	C	X	3	1	4			
Atriplex obovata	S	2	D	W	D	W	2	C	X	3	1	4			
Atriplex torreyi	S	2	D	W	D	W	2	C	X	2	1	3			
Ceratoides lanata	S	2	M	W	D	W	2	D	X	22	23	45			
Grayia spinosa	S	2	M	W	D	W	2	C	X	22	18	40			
Kochia americana	SS	1	P	W	D	W	2	C	X	10	18	28			
Sarcobatus vermiculatus	S	2	M	W	D	W	2	D	X	11	26	37			
Suaeda torreyana	S	2	P	W	D	W	2	C	X	10	18	28			
Zuckia brandegei	S	2	M	W	D	W	2	C	X	12	9	21			
Cornaceae															
Cornus sericea	S	3	P	A	Fl	Fl	3	C	U	18	28	46	O	W	R
Elaeagnaceae															
Elaeagnus commutata	S	2	Po	A	Fl	Fl	4	C	X	7	2	9	O	Y	R
Shepherdia argentea	S	3	D	A	Fl	Fl	3	C	X	10	15	25	O	B	R
Shepherdia canadensis	S	2	D	W	Fl	Fl	3	U	U	13	17	30			
Shepherdia rotundifolia	S	2	D	W	Fl	A	4	U	X	15	7	22			
Ericaceae															
Arctostaphylos patula	S	1	P	A	Fl	A	3	C	U	15	18	33	R	P	R
Arctostaphylos pringlei	S	2	P	A	Fl	Fl	3	U	U	11	1	12	R	P	R
Arctostaphylos pungens	S	2	P	A	Fl	Fl	3	U	U	10	2	12	R	P	R
Arctostaphylos uva-ursi	S	1	P	A	Fl	Fl	3	C	U	15	9	24	R	P	R
Gaultheria humifusa	SS	1	P	A	Fl	A	1	U	X	6	2	8	S	P	R
Kalmia microphylla	S	1	P	A	D	W	1	U	X	9	4	13	S	P	R
Ledum glandulosum	S	2	P	A	D	W	1	U	X	8	4	12	O	W	R
Vaccinium caespitosum	SS	1	P	A	Dl	Fl	2	C	U	13	8	21	R	P	R
Vaccinium membranaceum	S	2	P	A	Fl	Fl	2	D	U	7	6	13	R	P	R
Vaccinium myrtillus	S	1	P	A	Fl	Fl	2	U	U	12	5	17	S	P	R
Vaccinium occidentale	S	2	P	A	Fl	Fl	2	C	X	8	4	12	S	P	R
Vaccinium scoparium	SS	1	P	A	Fl	Fl	2	D	U	11	7	18	S	P	R
Fabaceae															
Acacia greggii	ST	3	P	A	D	A	4	C	O	1	1	2	O	G	R
Caesalpinia gilliesii	ST	3	P	A	D	A	3	U	O	5	4	9	R	P	B
Parryella filifolia	S	2	P	A	D	A	3	U	X	2	2	4	O	Y	R
Prosopis glandulosa	ST	3	P	A	D	A	4	C	X	6	1	7	O	G	R
Prosopis pubescens	ST	3	P	A	D	A	2	U	X	3	1	4	O	Y	R
Psorothamnus arborescens	S	2	P	A	D	A	3	U	X	4	1	5	R	Bl	B
Psorothamnus fremontii	S	2	P	A	D	A	3	C	X	17	4	21	R	Bl	B

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Psorothamnus polydenius	S	2	P	A	D	A	3	C	X	4	2	6	R	Bl	B
Psorothamnus thompsonae	S	2	P	A	D	A	3	U	X	12	5	17	R	Bl	B
Robinia neomexicana	ST	3	P	A	D	A	4	C	U	8	1	9	R	P	B
Fagaceae															
Quercus eastwoodiae	ST	3	M	W	D	A	6	U	X	8	4	12			
Quercus gambelii	ST	3	M	W	D	A	6	D	O	17	26	43			
Quercus havardii	S	2	M	W	D	A	6	C	X	2	6	8			
Quercus pauciloba	ST	3	M	W	D	A	6	U	X	9	10	19			
Quercus turbinella	S	2	M	W	D	A	6	D	O	10	3	13			
Garryaceae															
Garrya flavescens	S	2	D	W	Fl	A	3	C	O	13	1	14			
Hydrophyllaceae															
Eriodictyon argustifolium	S	2	P	A	D	DC	2	C	X	15	1	16	S	W	R
Krameriaceae															
Krameria grayi	S	2	P	A	D	ST	3	U	X	6	1	7	O	Y	B
Krameria parvifolia	S	2	P	A	D	ST	4	U	X	4	1	5	O	Y	B
Lamiaceae															
Poliomintha incana	S	2	P	A	D	W	3	C	X	8	6	14	R	Pu	B
Salazaria mexicana	S	2	P	A	D	W	3	U	X	6	1	7	R	Pu	B
Salvia dorii	S	2	P	A	D	W	3	U	X	19	8	27	R	Pu	B
Loasaceae															
Eucnide urens	SS	2	P	A	D	W	1	U	X	3	1	4	O	Y	R
Mentzelia shultziorum	SS	2	P	A	D	W	3	U	X	4	1	5	O	Y	R
Petalonyx nitidus	SS	2	P	A	D	DC	2	U	X	1	1	2	R	W	R
Petalonyx parryi	S	2	P	A	D	DC	2	U	X	2	1	3	R	W	R
Oleaceae															
Forestiera pubescens	S	2	D	W	Fl	Fl	3	C	X	8	5	13			
Fraxinus anomala	ST	3	P	W	D	W	5	U	X	18	9	27			
Fraxinus velutina	T	4	M	W	D	W	5	C	O	11	2	13			
Menodora scabra	SS	2	P	A	D	A	3	U	X	4	3	7	O	Y	R
Menodora spinescens	SS	2	P	A	D	A	3	U	X	2	1	3	R	W	R
Polemoniaceae															
Gilia congesta var. frutescens	SS	2	P	A	D	DC	2	U	X	12	4	16	R	W	R
Gilia roseata	SS	2	P	A	D	DC	3	U	X	12	6	18	R	W	R
Leptodactylon pungens	S	2	P	A	D	DC	2	C	X	14	18	32	R	W	R
Leptodactylon watsonii	SS	1	P	A	D	DC	2	U	X	20	12	32	R	W	R
Linanthastrum nuttallii	SS	1	P	A	D	DC	2	U	X	20	7	27	R	W	R
Polygalaceae															
Polygala acanthoclada	S	2	P	A	D	W	2	U	U	10	7	17	O	W	B
Polygala subspinosa	SS	1	P	A	D	W	3	U	U	11	13	24	O	P	B
Polygonaceae															
Eriogonum bicolor	S	1	P	A	D	W	2	U	X	8	7	15	O	W	R
Eriogonum clavellatum	S	1	P	A	D	W	2	C	X	5	1	6	S	W	R
Eriogonum contortum	S	1	P	A	D	W	2	U	X	3	1	4	O	Y	R
Eriogonum corymbosum	S	2	P	A	D	W	2	C	X	17	14	31	O	W	R
Eriogonum fasciculatum	S	2	P	A	D	W	2	C	X	9	1	10	O	W	R
Eriogonum heermannii	S	2	P	A	D	W	2	U	X	10	1	11	O	W	R
Eriogonum heracleoides	S	2	P	A	D	W	3	U	X	19	14	33	O	W	R
Eriogonum leptocladon	S	2	P	A	D	W	2	C	X	7	7	14	O	W	R
Eriogonum leptophyllum	S	2	P	A	D	W	3	U	X	1	1	2	O	W	R
Eriogonum lonchophyllum	S	2	P	A	D	W	2	U	X	9	3	12	O	W	R
Eriogonum microthecum	S	2	P	A	D	W	2	U	X	19	21	40	O	W	R
Eriogonum nummulare	S	2	P	A	D	W	2	U	X	10	5	15	O	W	R
Eriogonum plumatella	S	2	P	A	D	W	2	U	X	1	1	2	O	W	R
Eriogonum thompsonae	S	2	P	A	D	W	2	U	X	8	2	10	O	Y	R
Eriogonum umbellatum	SS	2	D	A	D	W	3	U	X	24	23	47	O	W	R
Pyrolaceae															
Chimaphila menziesii	SS	1	P	A	D	DC	1	U	U	1	1	2	O	W	R
Ranunculaceae															
Clematis columbiana	V		P	A	D	W	2	U	U	6	19	25	O	Bl	R
Clematis ligusticifolia	V		D	A	D	W	2	U	O	14	23	37	O	W	R
Clematis occidentalis	V		P	A	D	W	2	U	U	8	7	15	O	Bl	R
Rhamnaceae															
Ceanothus fendleri	S	2	P	A	D	DC	3	U	U	9	11	20	O	W	R
Ceanothus greggii	S	2	P	A	D	DC	3	U	U	18	5	23	O	W	R

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ceanothus martinii	S	2	P	A	D	DC	3	U	U	12	17	29	O	W	R
Ceanothus velutinus	S	2	P	A	D	DC	2	D	O	11	13	24	O	W	R
Rhamnus alnifolia	S	2	D	W	Fl	Fl	3	U	X	1	2	3			
Rhamnus betulifolia	S	2	P	W	Fl	Fl	4	U	X	9	7	16			
Rosaceae															
Amelanchier alnifolia	ST	3	P	A	Fl	Fl	3	C	O	18	28	46	O	W	R
Amelanchier utahensis	S	3	P	A	Fl	Fl	3	C	O	20	28	48	O	W	R
Cercocarpus intricatus	S	2	P	W	D	W	3	U	X	11	17	28			
Cercocarpus ledifolius	ST	3	P	W	D	W	5	C	O	17	28	45			
Cercocarpus montanus	S	3	P	W	D	W	5	D	O	15	26	41			
Chamaebatiaria millefolium	S	2	P	A	D	W	3	U	O	15	11	26	O	W	R
Coleogyne ramosissima	S	2	P	A	D	A	3	D	X	11	7	18	O	Y	R
Crataegus chrysocarpa	ST	3	P	A	Fl	Fl	4	U	O	1	1	2	O	W	R
Crataegus douglasii	ST	3	P	A	Fl	Fl	3	C	U	11	20	31	O	W	R
Crataegus succulenta	ST	3	P	A	Fl	Fl	4	U	O	3	1	4	O	W	R
Dryas octopetala	S	1	P	A	D	W	2	C	X	6	4	10	O	W	R
Fallugia paradoxa	S	2	D	A	D	W	2	C	X	15	7	22	O	W	R
Holodiscus dumosus	S	2	P	A	D	W	2	U	X	24	28	52	O	W	R
Peraphyllum ramosissimum	S	2	P	A	Fl	A	3	U	X	11	13	24	O	P	R
Petrophytum caespitosum	SS	1	P	A	D	DC	2	U	X	21	18	39	O	W	R
Physocarpus alternans	S	2	P	A	D	DC	2	U	X	9	16	25	O	W	R
Physocarpus malvaceus	S	2	P	A	D	DC	2	D	U	18	13	31	O	W	R
Physocarpus monogynus	S	2	P	A	D	DC	2	U	U	6	2	8	O	W	R
Potentilla fruticosa	S	2	P	A	D	A	2	C	U	19	23	42	O	Y	R
Prunus americana	S	3	P	A	Fl	Fl	6	U	X	5	8	13	O	W	R
Prunus emarginata	ST	3	P	A	Fl	Fl	4	U	U	1	1	2	O	W	R
Prunus fasciculata	S	2	PoD	A	D	A	4	C	X	13	4	17	O	W	R
Prunus virginiana	ST	3	P	A	Fl	Fl	4	C	O	18	28	46	O	W	R
Purshia glandulosa	S	2	P	A	D	A	3	D	X	4	1	5	O	Y	R
Purshia mexicana	ST	3	P	A	D	W	3	C	X	18	19	37	O	W	R
Purshia tridentata	S	2	P	A	D	A	3	C	X	17	28	45	O	Y	R
Rosa nutkana	S	2	P	A	Fl	Fl	3	U	U	20	26	46	O	P	R
Rosa woodsii	S	2	P	A	Fl	Fl	3	U	U	26	28	54	O	P	R
Rubus idaeus	S	2	P	A	Fl	Fl	2	U	X	14	28	42	O	W	R
Rubus leucodermis	S	2	P	A	Fl	Fl	2	U	U	11	7	18	O	W	R
Rubus neomexicanus	S	2	P	A	Fl	Fl	2	U	X	2	1	3	O	W	R
Rubus parviflorus	S	2	P	A	Fl	Fl	2	U	U	14	14	28	O	W	R
Sorbus scopulina	S	3	P	A	Fl	Fl	3	U	U	9	13	22	O	W	R
Rubiaceae															
Galium multiflorum	SS	2	D	A	D	ST	2	U	X	17	21	38	S	Y	R
Galium stellatum	S	2	D	A	D	ST	2	U	X	3	1	4	S	Y	R
Rutaceae															
Ptelea trifoliata ssp. *pallida*	ST	3	PoD	A	D	W	4	U	X	4	3	7	O	W	R
Thamnosma montana	S	2	P	A	D	A	3	C	U	6	2	8	S	Pu	R
Salicaceae															
Populus acuminata	T	4	D	W	D	MW	2	C	O	6	15	21			
Populus angustifolia	T	4	D	W	D	MW	2	C	O	10	28	38			
Populus balsamifera	T	4	D	W	D	MW	2	C	O	11	7	18			
Populus fremontii	T	4	D	W	D	MW	2	C	O	12	15	27			
Populus tremuloides	T	4	D	W	D	MW	2	D	O	19	28	47			
Salix amygdaloides	ST	3	D	A(W)	D	MW	1	C	O	7	15	22	O	G	R
Salix arctica	S	1	D	A(W)	D	MW	1	U	X	9	7	16	O	B	R
Salix bebbiana	S	3	D	A(W)	D	MW	1	U	X	14	19	33	O	G	R
Salix boothii	S	3	D	A(W)	D	MW	1	U	X	11	20	31	O	B	R
Salix brachycarpa	S	2	D	A(W)	D	MW	1	U	X	12	14	26	O	G	R
Salix cascadensis	SS	1	D	A(W)	D	MW	1	U	X	6	4	10	O	B	R
Salix drummondiana	S	3	D	A(W)	D	MW	1	U	X	13	16	29	O	B	R
Salix exigua	S	3	D	A(W)	D	MW	1	C	X	19	28	47	O	G	R
Salix geyeriana	S	3	D	A(W)	D	MW	1	C	O	8	16	24	O	B	R
Salix glauca	S	2	D	A(W)	D	MW	1	C	O	10	8	18	O	B	R
Salix gooddingii	T	4	D	A(W)	D	MW	1	C	O	9	5	14	O	G	R
Salix laevigata	T	4	D	A(W)	D	MW	1	C	O	8	3	11	O	Y	R
Salix lasiandra	ST	3	D	A(W)	D	MW	1	C	O	12	23	35	O	G	R
Salix lasiolepis	ST	3	D	A(W)	D	MW	1	C	O	9	9	18	O	B	R
Salix lutea	S	3	D	A(W)	D	MW	1	C	O	12	23	35	O	B	R

(con.)

	Characteristic														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salix monticola	S	3	D	A(W)	D	MW	1	C	X	11	8	19	O	B	R
Salix planifolia	S	2	D	A(W)	D	MW	1	C	U	15	10	25	O	B	R
Salix reticulata	S	1	D	A(W)	D	MW	1	U	X	11	7	18	O	G	R
Salix scouleriana	ST	3	D	A(W)	D	MW	1	U	U	21	22	43	O	B	R
Salix wolfii	S	2	D	A(W)	D	MW	1	U	X	9	7	16	O	B	R
Saxifragaceae															
Fendlera rupicola	S	2	P	A	D	DC	4	U	X	4	2	6	O	W	R
Fendlera utahensis	S	2	P	A	D	DC	2	U	X	14	6	20	O	W	R
Jamesia americana	S	2	P	A	D	DC	2	U	X	21	5	26	O	W	R
Phyladelphus microphyllus	S	2	P	A	D	DC	2	U	X	16	16	32	O	W	R
Ribes aureum	S	3	P	A	Fl	Fl	3	C	X	14	26	40	R	Y	R
Ribes cereum	S	2	P	A	Fl	Fl	2	C	X	19	27	46	R	W	R
Ribes hudsonianum	S	2	P	A	Fl	Fl	2	U	X	9	6	15	O	W	R
Ribes inerme	S	2	P	A	Fl	Fl	2	U	X	14	18	32	S	W	R
Ribes lacustre	S	2	P	A	Fl	Fl	2	U	X	14	4	18	O	Pu	R
Ribes laxiflorum	S	2	P	A	Fl	Fl	2	U	X	3	1	4	O	Pu	R
Ribes leptanthum	S	2	P	A	Fl	Fl	2	U	X	9	7	16	S	W	R
Ribes montigenum	S	2	P	A	Fl	Fl	2	C	U	17	24	41	O	Pu	R
Ribes setosum	S	2	P	A	Fl	Fl	3	U	X	8	4	12	R	W	R
Ribes velutinum	S	2	P	A	Fl	Fl	2	C	X	10	5	15	S	W	R
Ribes viscosissimum	S	2	P	A	Fl	Fl	3	U	U	10	16	26	R	W	R
Ribes wolfii	S	2	P	A	Fl	Fl	2	U	X	19	11	30	S	W	R
Scrophulariaceae															
Penstemon ambiguous	SS	2	P	A	D	DC	2	U	X	13	5	18	R	P	B
Penstemon caespitosus var. *suffruticosus*	SS	1	P	A	D	DC	2	U	X	10	5	15	R	Bl	B
Penstemon deustus	SS	1	P	A	D	DC	2	U	X	8	1	9	R	W	B
Penstemon petiolatus	SS	1	P	A	D	DC	2	U	X	16	1	17	R	Bl	B
Penstemon linarioides	SS	1	P	A	D	DC	2	U	X	5	4	9	R	P	B
Solanaceae															
Lycium andersonii	S	2	P	A	Fl	Fl	2	C	X	15	8	23	R	W	R
Lycium cooperi	S	2	P	A	Fl	Fl	2	U	X	4	1	5	R	W	R
Lycium pallidium	S	2	P	A	Fl	Fl	2	U	X	10	5	15	R	G	R
Lycium torreyi	S	2	P	A	Fl	Fl	2	U	X	5	2	7	R	Pu	R
Ulmaceae															
Celtis reticulata	ST	3	M	W	Fl	Fl	3	U	O	7	16	23			
Verbenaceae															
Aloysia wrightii	S	2	P	A	D	W	2	U	X	1	1	2	S	W	B
Vitaceae															
Parthenocissus vitaceae	V		Po	W	Fl	Fl	3	U	O	3	3	6			
Vitis arizonica	V		PoD	W	Fl	Fl	3	C	O	6	1	7			
Zygophyllaceae															
Larrea tridentata	S	2	P	A	D	W	3	D	O	5	1	6	O	Y	R

A RELATIONSHIP BETWEEN POLYPLOIDY AND HABITAT IN WESTERN SHRUB SPECIES

Stewart C. Sanderson, E. Durant McArthur, and Howard C. Stutz

ABSTRACT: The relationships between polyploidy and physiological stress and polyploidy and the *gigas* syndrome were re-examined by considering data from western wildland shrubs. In general, these shrubs give renewed credence to Hagerup's Hypothesis (for at least some situations) that polyploids are better adapted to ecologically stressful environments than their diploid relatives. In contrast to the traditional *gigas* syndrome associated with the polyploid state of herbaceous plants, the shrubs *Artemisia tridentata*, *Atriplex canescens*, *A. confertifolia*, and *Chrysothamnus viscidiflorus* are more robust as diploids. A lower rate of cell division and growth has generally been observed for polyploid tissues, and may be selectively advantageous where moisture supplies are insufficient for the support of taller statures. However, a U-shaped curve for plant height was observed over a larger range of ploidies (2x-10x) available in *A. confertifolia* in Western Utah. While diploids in this area were located on well-drained slopes, polyploid populations occurred on saline lowlands, often with higher water tables. Measurements of electrical conductivity of soils and of leaf extracts for these populations suggest an increase of osmotic capability with ploidy.

INTRODUCTION

This study and accompanying review were undertaken because we have observed that some western shrub genera, notably *Artemisia* and *Atriplex*, have giant diploid forms that are adapted to more mesic habitats, in general, than many of their polyploid relatives (Stutz and others 1975; Stutz and Sanderson 1979, 1983; Barker and McKell 1981; McArthur and others 1981; McArthur and Welch 1982; Dunford 1984). We felt this information would have some bearing on a longstanding controversy on physiological adaptation of the polyploid state. Hagerup (1932) suggested that polyploids were better adapted to extreme ecological environments than were their diploid relatives. This hypothesis has been supported by investigators and reviewers of several taxa over a broad geographical range (Tischler 1935, 1937; Wulff 1937; Löve and Löve 1943, 1957; Johnson and Packer 1965). On the other hand, Bowden (1940), Gustafsson (1948), Stebbins (1950, 1971), and Powell and Sloan (1975) have opposed Hagerup's Hypothesis in favor of an alternate suggestion by Stebbins (1950) that increasing polyploid frequencies have resulted from a selective advantage of highly heterozygous polyploids in unstable environments. In recent reviews both Grant (1971) and Lewis (1980) recognized the validity of Stebbins' Hypothesis that increased polyploid frequencies do result from unstable environments but both reviewers also acknowledged possible merit in Hagerup's Hypothesis especially as championed by the Löves. It has been shown conclusively that both diploid and polyploid species can have broad ecological adaption (Stebbins 1971)--Hancock and Bringhurst's 1978 and 1979 examples of diploid and octoploid *Fragaria* species, respectively, are illustrative.

In this paper we: (1) briefly review the relationship between polyploidy and habitat of several western wildland shrub species adapted to semi-arid conditions, and (2) present stature, water status, and other measurements for two species (*Artemisia tridentata* and *Atriplex confertifolia*) each of which have contiguous diploid and polyploid populations and for which we have studied chromosome number distribution (McArthur and others 1981; Stutz and Sanderson 1983; McArthur and Sanderson 1987). We consider relationships between habitat, ploidy, and growth habit. We were particularly interested in the distribution of giant (*gigas*) growth habit. The *gigas* habit has been best characterized in herbaceous plants and attributed as a function of polyploidy (Smith 1946; Solbrig 1971; Lewis 1981). However, in earlier publications (Stutz and others 1975; McArthur and Welch 1982; Stutz and Sanderson 1983) we presented evidence that some western wildland shrubs have a more robust form associated with diploidy.

Artemisia tridentata ssp. *wyomingensis* (tetraploid) is a shrub of arid valley slopes and is usually 3 feet in height or less, while *A. t. tridentata* (diploid) which grows adjacent to arroyos and in other locations of higher moisture availability has been measured as much as 15.6 feet in height (McArthur and Welch 1982). Monsen and McArthur (1985) documented a lower level of annual precipitation for ssp. *wyomingensis* (34.8 ± 2.3 cm$_{se}$) than for ssp. *tridentata* (45.3 ± 3.6 cm$_{se}$). *Atriplex canescens* diploids, which are found chiefly in sandy situations, are mostly

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Stewart C. Sanderson is Research Associate, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, and Brigham Young University, Provo, UT; E. Durant McArthur is Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT; Howard C. Stutz is Professor Emeritus, Department of Botany and Range Science, Brigham Young University, Provo, UT.

taller than tetraploids (Stutz and others 1979). Diploids of *Atriplex confertifolia* are found elevationally higher and are generally taller than tetraploids (Stutz and Sanderson 1983).

Data available for polyploid western shrub taxa suggest that as a generality diploids are larger and grow in more mesic habitats than do related polyploids (table 1). In six of the 10 taxa (*Ambrosia dumosa*, *Artemisia tridentata*, *Atriplex canescens*, *A. confertifolia*, *Chrysothamnus viscidiflorus*, *Larrea tridentata*) diploids are adapted either on local or regional scales to more mesic habitats than are polyploids. The other four taxa listed in table 1 (*Arctostaphylos* spp. *Grayia brandegei*, *Gutierrezia sarothrae*, *Sarcobatus vermiculatus*) apparently do not follow ploidy/moisture gradients although *Sarcobatus* includes a diminutive species, *S. baileyi*, which is a high polyploid and grows on more xeric sites

Table 1--Generalized ploidy, growth habit, and habitat relationships in some western wildland shrubs

Taxon	Chromosome races			References
	Ploidy	Growth habit	Habitat preference	
Ambrosia dumosa x = 18[2]	2x	--[1]	widespread	Raven and others 1969
	4x	--	widespread	
	6x	--	widespread	
Arctostaphylos spp. x = 13	2x	--	variable	Wells 1968
	4x	--	variable	
Artemisia tridentata[3] x = 9	2x	large	mesic	McArthur and Welch 1982; Barker and McKell 1983, 1986; this paper
	4x	smaller	drier	
Atriplex canescens x = 9	2x	largest	mesic	Stutz and others 1975; Stutz and Sanderson 1979; Dunford 1984, 1985
	4x	smaller	drier	
	6x	smallest	drier	
	12x	smaller	driest	
Atriplex confertifolia x = 9	2x	large	mesic	Stutz and Sanderson 1983; this paper
	4x	variable	drier	
	6x	variable	saline	
	8x	variable	saline	
	10x	largest	saline	
Chrysothamnus viscidiflorus x = 9	2x	largest	dry	Anderson 1986
	4x	smaller	drier	
	6x	smallest	driest	
Grayia brandegei x = 9	2x	smaller	restricted	Stutz and others 1987
	4x	larger	wider	
Gutierrezia sarothrae x = 4	2x	smaller	mixed 2x-4x populations	Solbrig 1977
	4x	larger	mixed 2x-4x populations	
Larrea tridentata x = 13	2x	--	dry	Yang 1970; Hunziker and others 1977
	4x	--	drier	
	6x	--	driest	
Sarcobatus vermiculatus x = 18[2]	4x	--	northern	Roos 1984
	6x	--	southern	

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[1] Indicates no data available or no detectable differences between ploidy levels.

[2] Base number is probably x = 9 but no diploids at that level have been discovered.

[3] Taxon includes four subspecies. For details see McArthur and others 1979 and Goodrich and others 1985. 6x populations reported by McArthur and others (1981) are an undescribed stabilized hybrid between *A. tridentata* and *A. arbuscula* (Winward and others 1986).

than does *S. vermiculatus* (Stutz 1987). The large stature-diploid syndrome of western wildland shrubs clearly includes *Artemisia tridentata*, *Atriplex canescens*, *A. confertifolia*, and *Chrysothamnus viscidiflorus*. It is suggested that a lowering of growth in polyploid shrubs, allowing an increased ability to survive in situations of limited soil moisture, has allowed the origin of drought-resistant forms from a more mesically adapted diploid ancestry.

Further evidence for such a diploid/mesic habitat interpretation comes from *Artemisia* and *Atriplex* congeners growing in Eurasia and Australia, respectively. *Artemisia santonicum* has fast-growing diploids and slower growing polyploids (Persson 1974). *Atriplex vesicaria* includes diploid, tetraploid, and hexaploid chromosome races (Nobs 1980) and populations of differential stature (Parr-Smith and Calder 1979) although the ploidy/growth habit correlations have not been made. That the tall and fast growth rate of diploids has a strong genetic component is demonstrated in common garden studies (Stutz and others 1975; McArthur and Welch 1982; McArthur and others 1983; Jones and others 1987). Clear exceptions to the giant diploid syndrome are *Grayia brandegei* and *Gutierrezia sarothrae* (table 1). In both of these cases tetraploids are larger than diploids. We believe it is interesting that these species are more nearly herbaceous, with which growth form the *gigas* polyploid syndrome has traditionally been associated. *Grayia brandegei* and *Gutierrezia sarothrae* are suffrutescent shrubs, the latter with close herbaceous relatives (McArthur and others 1979; Solbrig 1977). Suffrutescent *Atriplex* ssp. (*A. gardeneri* complex), studied by Pope (1976) and Stutz and others (1979) but not included in table 1 have larger diploids of mesic habitat for some phylogenetic lines but not others (Stutz and Sanderson 1986).

MATERIALS AND METHODS

At individual study sites, healthy mature plants were randomly selected for study. Data collected included shrub heights (cm) and pressure bomb measurements (MPa) of shrub twig water potentials (Waring and Cleary 1967; Freeman and McArthur 1982). Water potential data were collected during the afternoons of the week of September 21, 1987 after a period of several weeks without rain. Skies were sunny or had high, thin clouds on each day of measurement.

Water potential measurements at *Artemisia tridentata* sites were made by alternately measuring a plant of one ploidy level and then one of the other. *Artemisia tridentata* was examined at two locations, at one-half mile west of Sage, Lincoln County, and at the north foot of South Table Mountain, Sweetwater County, in Wyoming, on September 25 and 26, 1987, respectively. The diploid plants in this study were *A. tridentata* ssp. *tridentata* whereas the tetraploid ones were *A. tridentata* ssp. *wyomingensis*. The subspecies have differences but are closely related and share a common karotype (McArthur and others 1979, 1981; McArthur and Welch 1982).

Atriplex confertifolia ploidy races did not occur sympatrically and therefore sites with different ploidy levels in a given area were sampled sequentially. At the first, Rush Valley, 10 individuals were measured for each ploidy level, and afterwards the sites were revisited in the same sequence and 10 more individuals measured. No observable change occurred, therefore due to constraints of time and distance, measurement at the other two *A. confertifolia* areas were made for 20 individuals per site on single visits. Measurements for the three *A. confertifolia* areas were made on separate days. These were Rush Valley, Tooele Co., Skull Valley, Tooele Co., and Snake Valley, Millard Co., Utah, on September 22, 23, and 24, 1987. Diploids of the three series were located near the respective valleys at Fivemile Pass (for Rush Valley), Hastings Pass (for Skull Valley), and the U.S. Highway 6 Confusion Range Summit (for Snake Valley).

Measurements of soil properties (electrical conductivity, texture, pH) (Black 1968) and indication of depth of the water table (Kearney and others 1914; Roos 1984) were collected for each *A. confertifolia* site (table 2). Electrical conductivity measurements were made of leaf tissue of *A confertifolia* (table 3) from the Snake Valley populations. Leaves were oven dried at 40 °C, ground, and 0.1 g samples were further ground in a mortar and pestle with 2 ml water and centrifuged. Fifty microliters of the supernatant were diluted with 3 ml of water, giving a ratio of 0.83 mg leaf weight per ml solution.

Statistical analyses were performed using SAS analysis of variance (ANOVA) followed when appropriate by the Student-Newman-Kuels multiple range means comparison tests (SNK) (SAS Institute 1985).

RESULTS

As in previous reports (McArthur and others 1979; McArthur and Welch 1982; Stutz and Sanderson 1983), diploids were significantly ($p < 0.05$) greater in plant height than tetraploids at all of the study areas and for both species (fig. 1, 2). Tetraploids and octoploids of *Atriplex confertifolia* were not consistently distinguishable, but the single decaploid population measured was larger in stature (fig. 2). Water potentials were less negative for diploids, even in *Artemisia tridentata* subspecies, where the two ploidy levels grew adjacent (South Table Mountain) or intermixed (Sage).

Soil electrical conductivity, a measure of salt concentration, was not significantly different for *A. confertifolia* ploidy levels at the sample size (one measurement per populations) (table 2). However soils for diploids ranged from 0.55 to 0.66×10^3, while those for polyploids were above 1.00×10^3 (table 2) and follow trends similar to

Table 2--Soil characteristics for sampled *Atriplex confertifolia* sites

Ploidy	Location	E.C.x 10^3	Percent sand	Percent clay	Percent silt	pH	Water table[1]
2x	Rush Valley	0.55	58	15	27	8.00	L
2x	Skull Valley	0.66	39	27	33	8.00	L
2x	Snake Valley	0.65	60	13	27	8.10	L
4x	Rush Valley	1.55	23	39	37	8.00	H
4x	Skull Valley	1.06	38	23	39	7.80	L
4x	Snake Valley	1.27	76	13	11	8.50	L
8x	Rush Valley	1.58	34	19	47	8.10	H
8x	Skull Valley	31.00	46	19	35	7.80	H
8x	Snake Valley	1.35	73	7	19	8.40	H
10x	Snake Valley	1.80	58	11	31	8.50	H

[1] High or low water tables as shown by presence of the indicator species *Sarcobatus vermiculatus*.

those observed previously (Stutz and Sanderson 1983).

Electrical conductivity of leaf extracts (table 3) was significantly lower for tetraploids and significantly higher for decaploids. However, because a sizable proportion of the ions measured would be those sequestered in leaf hairs (Osmond and others 1980) which at undetermined times break and release their contents, uncertainty exists as to concentration within the other parts of the leaf. Another measure of osmotic capability might have been obtained from betain and other quanternary ammonium compounds. Our attempt to assay these compounds as the periodides proved difficult due to chemical instability (Storey and Wynn Jones 1977).

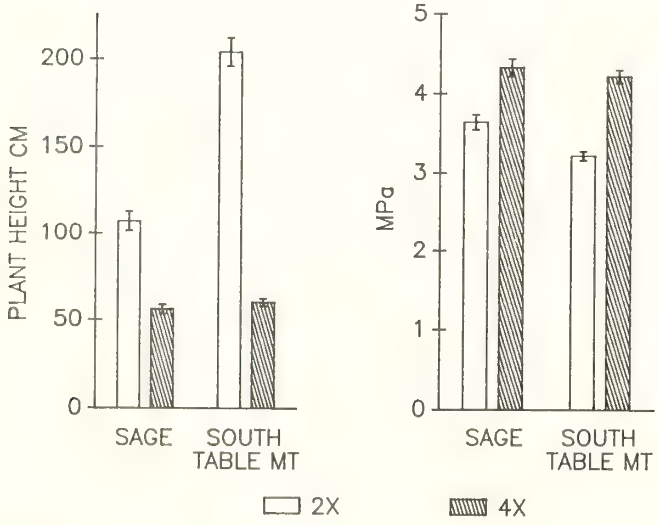

Figure 1--Plant height (left) and water potential (right) of *Artemisia tridentata* diploid (ssp. *tridentata*) and tetraploid (ssp. *wyomingensis*) plants at two sites in Wyoming, showing standard error.

DISCUSSION AND CONCLUSIONS

The cells of polyploids in comparison to those of diploids tend to be larger and their mitotic cycles slower (Stebbins 1950, 1971; Grant 1971), which often results in a larger macroscopic size of plant parts such as flowers and leaves, and sometimes of stature. However, at least in comparisons at the diploid and tetraploid levels, a stature relationship of this sort is not observed in natural populations of *Atriplex confertifolia* and *Artemisia tridentata*, nor in many woody species in which tetraploids are smaller than diploids (table 1). Further, Jones and others (1987) found that irrigated plants of *Artemisia tridentata* ssp. *wyomingensis* (tetraploid) in a common garden were much smaller and grew more slowly than those of ssp. *tridentata* (diploid). Because the cells of polyploids tend to grow more slowly, it is probably to be expected that shrubby polyploids should be smaller than diploids.

Reduced plant stature may be advantageous in relation to drought hardiness. Jones and others (1987) found that unirrigated diploid *Artemisia tridentata* ssp. *tridentata* plants growing in an experimental planting had more negative water potentials than tetraploid ssp. *wyomingensis*, likely because of a greater demand by these large plants on soil moisture. Subspecies *tridentata* is notable in its restriction to microhabitats of greater moisture availability, such as the banks of washes or in valley bottoms. In its more common habitats, as shown by Barker and McKell (1983) and in both of our *Artemisia* study sites, diploid plants had less extreme water potentials in an arid season than adjacent tetraploids. Jacobsen and Welch (1987) have shown differential root growth patterns between ssp. *wyomingensis* and *tridentata* plants under greenhouse conditions. Probably the large diploids were able to tap a water supply not reached by ssp. *wyomingensis* roots (but see also Richards and Caldwell 1987). Given an equivalent water supply there might have been no differences, as was reported for the two subspecies growing on sand

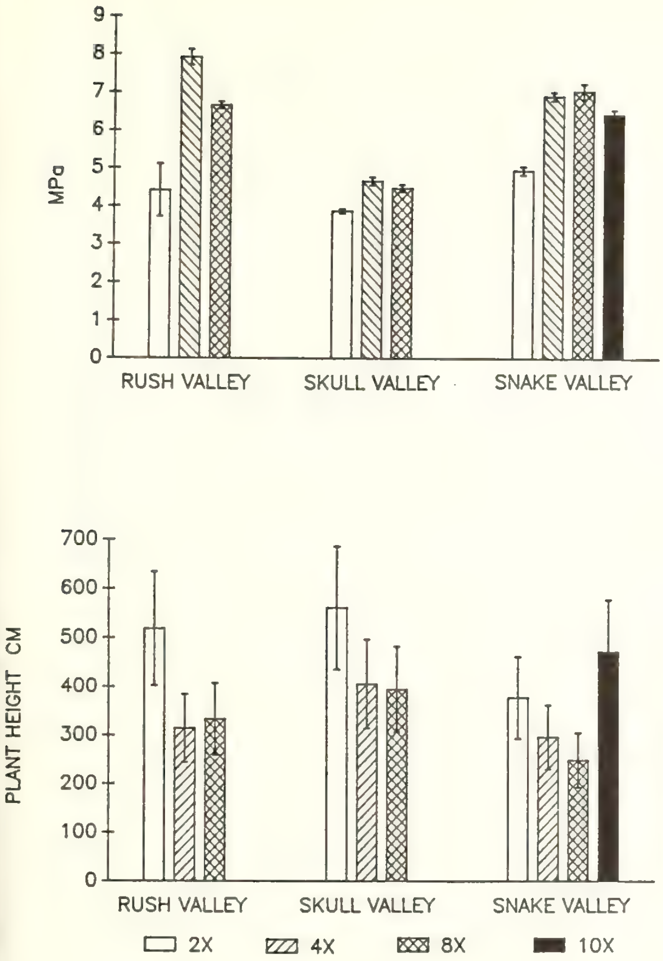

Figure 2--Water potential (above) and plant height (below) for diploids and polyploids and polyploids of Atriplex confertifolia at three areas in Western Utah, showing standard error.

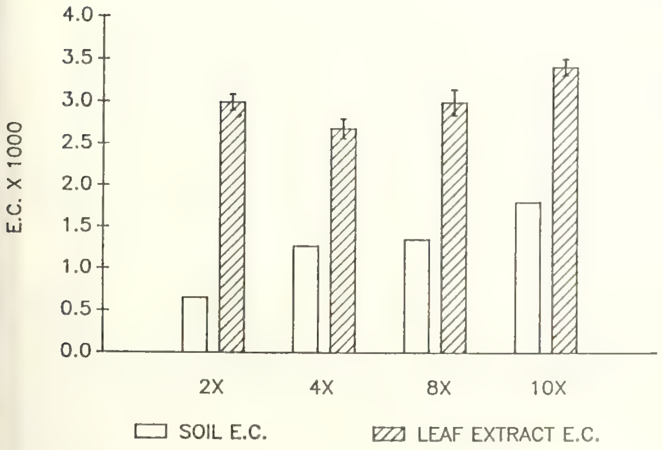

Figure 3--Relative soil and leaf extract electrical conductivity for four ploidy levels of Atriplex confertifolia, in Snake Valley. Leaf extracts were diluted to 0.83 mg dry weight/ml.

Table 3--Electrical conductivity of extracts of dried leaves of Atriplex confertifolia from Snake Valley, Millard County, UT. The ratio of dry weight to solution volume was 0.83 mg/ml

Ploidy	E.C. x 1-^{2} mean	n	SNK test[1]
2x	29.9	10	A B
4x	26.8	10	B
8x	29.9	10	A B
10x	34.1	10	A

[1] Means with the same letter are not significantly ($p < .05$) different.

dunes (Shumar and Anderson 1986). The smaller tetraploids would therefore probably fare better when on arid sites than diploids, which might tend to be eliminated.

As previously mentioned, diploids of Artemisia confertifolia likewise occupy more mesic sites than polyploids. Diploids of A. confertifolia at each of our three study areas occurred at higher altitudes than nearby polyploids and were the only populations occurring within arboreal vegetation zones (pinyon-juniper). Diploids were more robust, but not as dramatically so as the Artemisia tridentata diploids.

The presence of higher ploidy levels in Atriplex confertifolia allowed a continuation of measurements in that species up to the octoploid and decaploid levels. However, as previously discovered (Stutz and Sanderson 1983), instead of a continuation of the trend of decreasing stature, octoploids did not appear greatly different from tetraploids, and decaploids were taller than either (fig. 2). A possible reason for such a reversal of size relationships might be that there is an increased tolerance by polyploids of salinity (Tal and Giardi 1976; Tal 1980) as suggested by increased ionic content of leaf extracts at the highest ploidy (table 3, fig. 3). Polyploids of A. confertifolia often grow with Sarcobatus vermiculatus, an indicator of high (if saline) water tables (Kearney and others 1914; Meinzer 1937). This is particularly true of A. confertifolia decaploids. Water availability in such Sarcobatus areas, once a sufficient salt tolerance was present, might have allowed achievement of greater A. confertifolia statures.

The data collected here relate to stresses of arid climates and, in part, support Hagerup's Hypothesis. It seems probable for both Artemisia tridentata and Atriplex confertifolia that, through a reduced growth rate, tetraploids are more economical than diploids of moisture. In A. confertifolia in addition, there is a suggestion of greater salinity tolerance with increasing ploidy. Data from other physiologically stressful conditions, such as cold, may support Hagerup's Hypothesis as the Löves (1943, 1957) among others have suggested. We believe the intriguing question of ploidy/habitat relationships remains open.

REFERENCES

Anderson, L. C. 1986. Cytogeography of *Chrysothamnus viscidiflorus*. In: Proceedings--symposium on the biology of *Artemisia* and *Chrysothamnus*, 1984 July 9-13; Provo. UT. Gen. Tech. Rep. INT-200. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 93-97.

Barker, J. R.; McKell, C. M. 1983. Habitat differences between basin and Wyoming big sagebrush in contiguous populations. Journal of Range Management. 36: 450-454.

Barker, J. R.; McKell, C. M. 1986. Differences in big sagebrush (*Artemisia tridentata*) plant stature along soil-water gradients: genetic components. Journal of Range Management. 39: 147-151.

Bowden, W. M. 1940. Diploidy, polyploidy, and winter hardiness relationships in the flowering plants. American Journal of Botany. 27: 357-371.

Black, C. A. 1968. Soil-plant relationships. 2d ed. New York: Johnson Wiley and Sons. 792 p.

Dunford, M. P. 1984. Cytotype distribution of *Atriplex canescens* (Chenopodiaceae) of southern New Mexico and adjacent Texas. Southwestern Naturalist. 29: 223-228.

Dunford, M. P. 1985. A statistical analysis of morphological variation in cytotypes of *Atriplex canescens* (Chenopodiaceae). Southwestern Naturalist. 30: 377-384.

Freeman, D. C.; McArthur, E. D. 1982. A comparison of twig water stress between males and females of sex species of desert shrubs. Forest Science. 28: 304-308.

Goodrich, S.; McArthur, E. D.; Winward, A. H. 1985. A new combination and a new variety in *Artemisia tridentata*. Great Basin Naturalist. 45: 99-104.

Grant, V. 1971. Plant speciation. New York: Columbia University Press. 435 p.

Gustafsson, A. 1948. Polyploidy, life-form, and vegetative reproduction. Hereditas. 34: 1-22.

Hagerup, O. 1932. Uber Polyploidie in Biziehung zu Klima, Okologie, und Phylogenie. Hereditas. 16: 19-40.

Hancock, J. F., Jr.; Bringhurst, R. S. 1978. Interpopulational differentiation and adaptation in the perennial, diploid species *Fragaria vesca* L. American Journal of Botany. 65: 795-803.

Hancock, J. F., Jr.; Bringhurst, R. S. 1979. Ecological differentiation in perennial, octoploid species of *Fragaria*. American Journal of Botany. 66: 367-375.

Hunziker, J. H.; Palacios, R. A.; Poggio, L.; Naranjo, C. A.; Yang, T. W. 1977. Geographic distribution, morhpology, hybridization, cyctogenetics and evolution. In: Mabry, T. J.; Hunziker, J. H.; DiFeo, D. R.; eds. Creosote bush, biology and chemistry of *Larrea* in New World deserts. US/IBP Synthesis Series 6. Stroudsburg, PA: Dowden, Hutchinson, and Ross, Inc.: 10-46.

Johnson, A. W.; Packer, J. G. 1965. Polyploidy and environment in arctic Alaska. Science. 148: 237-239.

Jones, M. A.; Shumar, M. L.; Anderson, J. E. 1987. Gas exchange characteristics of two subspecies of *Artemisia tridentata* under two watering regimes. Abstract--Fifth wildland shrub symposium, Shrub ecophysiology and biotechnology, June 30-July 2, 1987.

Kearney, K. T.; Briggs, L. J.; Shantz, H. L.; McLane, J. W.; Peimeisel, R. L. 1914. Indicator significance of vegetation of the Tooele Valley, Utah Journal of Agriculture Research. 1: 365-417.

Lewis, W. H. 1980. Polyploidy in species populations. In: Lewis, W. H., ed. Polyploidy, biological relevance. New York: Plenum Press: 103-144.

Löve, A.; Löve, D. 1943. The significance of differences in the distribution of diploids and polyploids. Hereditas. 29: 145-163.

Löve, A.; Löve, D. 1957. Arctic polyploidy. Proceedings Genetics Society of Canada. 2: 23-27.

McArthur, E. D.; Blauer, A. C.; Plummer, A. P., Stevens, R. 1979. Characteristics and hybridization of important Intermountain shrubs. III. Sunflower family. Res. Pap. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

McArthur, E. D.; Pope, C. L.; Freeman, D. C. 1981. Chromosomal studies of subgenus *Tridentatae* of *Artemisia*: evidence for autopolyploidy. American Journal of Botany. 68: 589-605.

McArthur, E. D.; Sanderson, S. C. 1987. *Artemisia* chromosome counts. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT.

McArthur, E. D.; Stevens, R.; Blauer, A. C. 1983. Growth performance comparisons among 18 accessions of fourwing saltbush (*Atriplex canescens*) at two sites in Central Utah. Journal of Range Management. 36: 78-81.

McArthur, E. D.; Welch, B. L. 1982. Growth rate differences among big sagebrush (*Artemisia tridentata*) accessions and subspecies. Journal of Range Management. 35: 396-401.

Meinzer, O. E. 1937. Plants as indicators of ground water. Water-supply paper 577. Washington, DC: U.S. Department of the Interior, Geological Survey. 95 p.

Monsen, S. B.; McArthur, E. D. 1985. Factors influencing establishment of seeded broadleaf herbs and shrubs following fire. In: Sanders, K.; Durham, J., eds. Rangeland fire effects, a symposium; 1984 November 27-29; Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 112-124.

Nobs, M. A. 1980. Chromosome number in Australian species of *Atriplex*. Carnegie Institution of Washington Year Book. 79: 164-169.

Osmond, C. B.; Bjorkman, O.; Anderson, D. J. 1980. Physiological processes in plant ecology: towards a synthesis with *Atriplex*. New York: Springer Verlag. 468 p.

Parr-Smith, G. A.; Calder, D. M. 1979. *Atriplex vesicaria* Heward ex. Benth. and related species: taxonomy and variation. In: Graetz, R. D.; Howes, K. M. W., eds. Studies of the Australian arid zone. IV. Chenopod shrublands. Melbourne: Commonwealth Sciences and Industrial Research Organization: 17-28.

Persson, K. 1974. Biosystematic studies in the *Artemisia maritima* complex in Europe. Opera Botanica. 35: 1-188.

Pope, C. L. 1976. A phylogenetic study of the suffrutescent shrubs in the genus *Atriplex*. Provo, UT: Brigham Young University. 277 p. Dissertation.

Powell, A. M.; Sloan, S. A. 1975. Polyploid percentages of gypsum and non-gypsum floras of the Chihuahuan Desert. Science of Biology Journal. 1: 37-38.

Raven, P. H.; Kyhos, D. W.; Breedlove, D. E.; Payne, W. W. 1968. Polyploidy in *Ambrosia dumosa* (Compositae: Ambrosieae). Brittonia. 20: 205-211.

Richards, J. H.; Caldwell, M. M. 1987. Hydraulic lift: substantial nocturnal water transport between soil layers by *Artemisia tridentata* roots. Ecologia. 73: 486-489.

Roos, R. C. 1984. Heritable variation in *Sarcobatus vermiculatus*. Provo, UT: Brigham Young University. 42 p. Thesis.

SAS Institute Inc. 1985. SAS/STAT guide for personal computers, version 6 edition. Cary, NC: SAS Institute. 378 p.

Shumar, M. L.; Anderson, J. E. 1986. Water relations of two subspecies of big sagebrush on sand dunes in Southeastern Idaho. Northwest Science. 60: 179-185.

Smith, H. E. 1946. *Sedum pulchellum*: a physiological and morphological comparison of diploid, tetraploid, and hexaploid races. Bulletin of the Torrey Botanical Club. 73: 495-451.

Solbrig, O. T. 1971. Polyphyletic origin of tetraploid populations of *Gutierrezia sarothrae* (Compositae). Madrono. 21: 20-25.

Solbrig, O. T. 1977. Chromosomal cytology and evolution in the family Compositae. In: Heywood, V. H.; Harborne, J. B.; Turner, B. L.; eds. The biology and chemistry of the Compositae. Vol. 1. London: Academic Press. 1189 p.

Stebbins, G. L. 1950. Variation and evolution in plants. New York: Columbia University Press. 643 p.

Stebbins, G. L. 1971. Chromosomal evolution in higher plants. London: Edward Arnold (Publishers) Ltd. 216 p.

Storey, R.; Wynn Jones, R. G. 1977. Quaternary ammonium compounds in plants in relation to salt resistance. Phytochemistry. 16: 447-453.

Stutz, H. C. 1987. *Sarcobatus* chromosome counts and morphological measurements. Data on file at: Brigham Young University, Department of Botany and Range Science, Provo, UT.

Stutz, H. C.; Melby, J. M.; Livingston, G. K. 1975. Evolutionary studies of *Atriplex*: a relic *gigas* diploid population of *Atriplex canescens*. American Journal of Botany. 62: 236-245.

Stutz, H. C.; Pope, C. L.; Sanderson, S. C. 1979. Evolutionary studies of *Atriplex*: adaptive products from the natural hybrid. 6N *A. tridentata* x 4N *A. canescens*. American Journal of Botany. 66: 1181-1193.

Stutz, H. C.; Sanderson, S. C. 1979. The role of polyploidy in the evolution of *Atriplex canescens*. In: Goodin, J. R.; Northington, D. K., eds. Arid land plant resources. Lubbock, TX: International Center for Arid and Semi-arid Land Studies, Texas Tech University: 615-621.

Stutz, H. C.; Sanderson, S. C. 1983. Evolutionary studies in *Atriplex*: chromosome races of shadscale (*Atriplex confertifolia*). American Journal of Botany. 70: 1536-1547.

Stutz, H. C.; Sanderson, S. C. 1986. *Atriplex* spp. chromosome and morphology data on file at: Brigham Young University, Department of Botany and Range Science, Provo, UT.

Stutz, H. C.; Sanderson, S. C.; McArthur, E. D.; Chu, G.-L. 1987. Chromosome races of Grayia brandegei (Chenopodiaceae). Madroño. 34: 142-149.

Tal, M. 1980. Physiology of polyploids. In: Lewis, W. H., ed. Polyploidy: biological relevance. New York: Plenum Press: 61-75.

Tal, M.; Gardi, I. 1976. Physiology of polyploid plants: water balance in autotetraploid and diploid tomato under low and high salinity. Physiologia Plantarum. 38: 257-261.

Tischler, G. 1935. Die Bedeutung der Ployploidie fur die Verbreitung der Angiospermen, erlautert and den Arten Schleswig Holsteins, mit Ausblicken auf andere Florengebiete. Botanusche Jahrbucher. 67: 1-36.

Tischler, G. 1937. Die Halligen flora der Nordsee im Lichte cytologischer Forschung. Cytologia. Jubilee Volume: 162-169.

Waring, R. H.; Cleary, B. D. 1967. Plant moisture stress; evaluation by pressure bomb. Science. 155: 1248-1254.

Welch, B. L.; Jacobson, T. L. C. 1987. Root growth of Artemisia tridentata. In review and on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT.

Wells, P. V. 1968. New taxa, combinations, and chromosome numbers in Arctostaphylos (Ericaceae). Madrono. 19: 193-210.

Winward, A. H.; McArthur, E. D.; Kaffer, D. A.; Plummer, C. A.; Brackley, G. K. 1986. Another sagebrush in Nevada. Technical Note-Range NV-44. Reno, NV: U.S. Department of Agriculture, Soil Conservation Service, Nevada State Office. 2 p.

Wulff, H. D. 1937. Karyologische Untersuchungen an der Halophyten-flora Schleswig-Holsteins. Jahrbucher fur Wissenschaftliche Botanik.

Yang, T. W. 1970. Major chromosome races of Larrea divaricata in North America. Journal of the Arizona Academy of Science. 6: 41-45.

CELLULAR AND MOLECULAR APPROACHES TO THE ECOPHYSIOLOGY AND GENETIC IMPROVEMENT OF SHRUBS

John G. Carman

ABSTRACT: Financially immense private and national efforts are being made to apply cellular and molecular biology to agriculture. These efforts have resulted in revolutionary methodologies that could be used by the ecophysiologist/biochemist for understanding shrubs and shrub-environment interactions and ultimately by the shrub breeder/geneticist to genetically enhance germplasm. In this review consideration is given to selected methodologies and their current applications in plant research. Ecophysiological applications are suggested as well as some reasonable, not so futuristic, applications for shrub improvement.

INTRODUCTION

With little doubt biotechnology's premier expression in the plant sciences will be the identification, manipulation and successful transfer of agriculturally (or ecologically) important genes. Recent breakthroughs hold promise for development of cultivars that express greater yield capacity; that express greater resistance to insects as well as viral, fungal and bacterial infections; and that are resistant to environmentally safer broad-spectrum herbicides. Such research and its applications have been the subject of many recent reviews (Hess 1987, Cocking and Davey 1987, Potrykus and others 1987, Phillips and others 1987, Baulcombe 1987, Keen 1986, Goodman and others 1987) and will not be addressed here. Rather, this review focuses on several of the spinoff technologies of the molecular and cellular biologist; technologies that could be used by the plant scientist to better understand the interactions of shrubs with their environments and, eventually, to genetically enhance a shrub's ability to successfully cope with severe environmental stresses and perturbations. Subjects addressed in this paper include restriction fragment length polymorphisms, hybridoma technology, transposon tagging and studies involving mRNA.

RESTRICTION FRAGMENT LENGTH POLYMORPHISMS

The purification of numerous enzymes that cut DNA at precise locations, based on a 4 to 7 base pair sequence (restriction enzymes), allows for the slicing of nuclear or plasmid DNA into fragments of specific lengths. Modern electrophoretic procedures permit separation of essentially homologous fragments that differ in length due to minor differences in base sequence at their restriction sites. Slight differences within or between organisms in the length of specific fragments can be detected by annealing labelled probes (RNA or cDNA), which are homologous to major portions of the fragments in question, to the electrophoretically separated DNA. Such polymorphisms in fragment length are referred to as restriction fragment length polymorphisms (RFLP's). RFLP's are codominantly inherited and, when represented in the plant in the heterozygous condition, can be mapped to other genetic loci by conventional methods (see Beckmann and Soller 1986). Linkage to previously mapped isozyme loci on tomato chromosomes has been accomplished for 120 different cDNA probes. The resultant linkage map now covers about 90% of the genome (Bernatzky and Tanksley 1986a, 1986b). Additional RFLP loci have been mapped to tomato chromosomes by Osborn and others (1987) and by Helentjaris and others (1986). The latter group also has greatly improved the chromosomal linkage maps of maize with the use of RFLP's.

Applications of RFLP's for evolutionary and genetic studies as well as for plant improvement are many. Until recently, quantification of polymorphisms for isozyme loci, as detected by differences in electrophoretic zymogram phenotypes, was considered the method of choice for determining extent of genetic variation within and between plant populations. Such variation has also been the subject of many taxonomic studies (see reviews in Tanksley and Orton 1983a and 1983b; Staub and others 1987). Today RFLP studies are rapidly replacing isozyme studies where such objectives are embraced. This is because the number of detectable RFLP's for a given taxon far exceeds the number of isozymes that could reasonably be used. Isozymes have other problems associated with them such as non-expression in certain tissues, possible differences between taxa in post-transcriptional modification, and questionable relevance in terms of natural selection. Restriction mapping and RFLP analyses of chloroplast DNA also provide meaningful information for systematic studies, especially

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John G. Carman is a plant geneticist with the Plant Science Department, Utah State University, Logan, UT 84322-4820.

at the intergeneric and higher levels of taxa differentiation (Dutta 1986a, 1986b).

Isozyme and RFLP loci can be used in similar ways for plant improvement. First, such loci if found to be linked to important traits can be used to select individuals from backcross populations that contain alleles for the desired traits. This approach is of special value in introgressive hybridization programs where screening for the desirable introgression phenotypes is costly or overly difficult. Similar approaches also can reasonably be applied to quantitative traits. Nienhuis and others (1987) found that specific alleles linked to four RFLP loci accounted for 38% of the phenotypic variance for 2-tridecanone (a compound implicated in insect resistance in tomato) in a carefully selected population of F_2's. Similarly, Osborn and others (1987) described linkage between RFLP loci and loci involved with soluble solids contents in tomato. These studies imply that potentially many RFLP loci can be correlated (or linked) with loci for quantitative traits such that accumulation of a select group of RFLP genotypes in a breeding program could result in individuals with maximal expression of the desired quantitative trait. Statistical procedures for such breeding schemes are already well developed (Stuber and others 1987; Nienhuis and others 1987; Edwards and others 1987; Beckmann and Soller 1986; Helentjaris and others 1985; Soller and Beckmann 1983). That restriction fragments homologous to sections of important genes can occasionally be isolated is evidenced by Vallejos and others (1986) who isolated fragments homologous with the rRNA (45s), the major chlorophyll A/B binding polypeptide and RuBP carboxylase genes.

It is evident from the above that there are several potential uses for RFLP's in shrub research. These include (1) high resolution in determining genetic variation and evolutionary divergence within and among taxa; (2) the rapid production of chromosome linkage maps, which should be most readily obtainable in outcrossing diploid species; and (3) use in breeding programs designed to introgress either simple or quantitative genetic traits among different genotypes.

HYBRIDOMA TECHNOLOGY

Hybridomas are monoclonal antibody-producing cells. They are generally produced by the fusion of an antibody-producing B-cell of an antigen-immunized animal with a myeloma cell, which renders the hybridoma potentially immortal. Many different hybridomas can be produced from an immunization with a specific antigen; the monoclonal antibodies of which may exhibit different properties, such as different levels of viral or enzyme inactivation (where the antigen was either a virus or an enzyme) or variable levels of specificity. Screening procedures are used to select, from members of a monoclonal library, monoclonals that exhibit desired properties. Such monoclonals can be labelled with an electron dense moiety for electron microscopy or with a radioactive moiety, biotin or a fluorochrome for light microscopy. Monoclonals so labelled can be used for the immunolocalization of antigenic surfaces in plant tissues or for quantification of specific biochemicals from plant extracts. A partial listing of plant-related antigens for which monoclonals have been raised appears in table 1. Procedures and other examples can be found in Gamble (1986).

Table 1--A partial listing of plant or plant-related substances for which monoclonal antibodies have been raised

Substance	Reference
Enzymes and proteins	
RuBP Carboxylase	(Vaughn 1987)
ferredoxin-nitrate reductase	(Ida 1987)
5-enolpyruvylshikimic acid 3-phosphate synthase	(Smart and Amrhein 1987)
phytochrome	(Schwarz and Schneider 1987; Silberman and others 1985)
wheat germ agglutinin	(Raikhel and Pratt 1987)
plasma membrane proteins	(Fitter and others 1987)
phloem lectin	(Smith and others 1987)
Plant growth regulators	
indoleacetic acid	(Mertens and others 1986)
gibberellic acids	(Knox and others 1987)
abscisic acid	(Raikhel and others 1986)
zeatin riboside	(Eberle and others 1986; Trione and others 1985, 1987)
Plant pathogens or parasites	
Chlamydomonas eugametos	(Homan and others 1987)
Xanthomonas campestris	(Yuen and others 1987; Leach and others 1987)
T-2 toxin of *Fusarium* spp.	(Gendloff and others 1987)
Erwinia amylovora	(Lin and others 1987)
wheat streak mosaic virus	(Sherwood 1987)
potato virus Y	(Rose and others 1987)
Others	
callose	(Grief and others 1987)

Labelled monoclonals for either microscopy or immunoassay generally provide results superior to those of other techniques. For example, Trione and others (1987), using a quantitative fluorescence enzyme immunoassay, quantified cytokinin levels as low as 0.03 pmol and Hainfeld (1987) electron microscopically visualized single antigen-binding antibody fragments by covalently linking an 11-atom gold cluster to such fragments. The number of plant-related antigens for which monoclonals have been produced is increasing as is the number of potential uses. Already, monoclonals for assaying plant growth regulators and some plant diseases are available commercially and study of plant-symbiont or plant-pathogen relationships using monoclonals or polyclonals (for the detection of additional molecular variants), including both infection sites and rates, is becoming commonplace. It is not unrealistic to suspect that monoclonals could be raised against the initial gene products that are produced by a shrub following an artificially imposed stress. Such monoclonals could then be used to study not only the initial gene products but also the sites and rates of stress response within and among genotypes.

TRANSPOSON TAGGING

Transposons (transposable elements) are DNA fragments that move in and out of chromosomes. In plants transposons range in length from about 0.4 to 8.3 kb (Doring and Starlinger 1986). Transposition of a transposable element into a gene (or its vicinity) generally causes a loss of gene function but on occasion can cause either an increase or decrease in gene function. Transposon-induced mutations frequently are unstable in that they can undergo germinal reversion, back to a wild type phenotype, at a rate as high as 2 to 3 percent. Such instability is a major diagnostic feature of transposons.

Recently, great interest has been placed upon the molecular isolation and cloning of transposons because once cloned they can be used to chemically isolate genes, for which knowledge of the gene product may or may not exist. Gene isolation by use of transposons (transposon tagging) involves the probing of restricted genomic DNA (from an organism in which a particular gene function has been altered by the insertion of a transposon) with labelled probes homologous to major portions of the transposon. By using a variety of restriction enzymes, it has been possible to extract and sequence entire genes from plant genomes (see Doring and Starlinger 1986 and Wienand 1986 for reviews). The cloning of genes tagged by transposons will likely be of immense value to the genetic engineering of plants. This is because one of the largest bottlenecks confronting the genetic engineering of plants is a lack of cloned agriculturally valuable genes.

It is believed that transposons are prevalent in plants (Nevers and others 1985; Vershinin and others 1987), particularly in natural populations of wild species where intense selection and breeding for uniformity has not occurred. Thus plant scientists involved in the selection or utilization of shrubs may on occasion observe germplasm suggestive of unstable mutations. Such germplasm should be made available to interested geneticists and biochemists who can evaluate their potential for the isolation of additional transposons as well as for the tagging to genes that may be of agricultural or ecological importance.

STUDIES INVOLVING mRNA

In general plants respond to environmental stresses by either initiating and/or terminating synthesis of specific mRNA's. There are two approaches that can be taken to detect or quantify the mRNA's involved. First, if the biochemistry of the response is known, or plausibly construed, and if cDNA probes exist, then such probes can be used to quantify differences in the rate of synthesis of specific mRNA's. This is accomplished by isolating RNA from affected plant tissues at different times after exposure to the stress, purifying the RNA and dividing it into aliquots of varied concentrations, and either electrophoretically separating the RNA on gels or dotting specific aliquots to nitrocellulose and probing either the dotted or separated RNA with the labelled probes. For example, Esnault and others (1987) used the dot hybridization procedure and observed a major increase in mRNA's for phenylalanine ammonialyase and chalcone synthase within three hours after inoculation of a resistant soybean cultivar with zoospores of Phytophthora megasperma f. sp. glycinea. No increase was observed in the susceptible cultivar. These results were consistent with differences in synthesis of glyceollin, an antifungal compound, between the two cultivars following inoculation.

Changes in the presence or quantity of major mRNA's can be established even if the biochemistry of the stress response is not understood. This is accomplished by purificaton and in vitro translation of mRNA's, at various times following initiation of a stress, followed by electrophoretic separation of the polypeptide products. Using this procedure, Collinge and others (1987) detected differential major changes in gene expression when lettuce was inoculated with Xanthomonas campestris pathovars that were known to induce either a hypersensitive or a compatible response. Purification of the major polypeptides followed by substrate analyses could possibly lead to a better understanding of the biochemistry of such poorly understood responses.

Various mRNA analyses could enhance our understanding of the shrub-environment interaction. For instance much is known at both the physiological and biochemical levels concerning the response of plants to drought and water-logging, other soil component excesses, herbivory, and high and low temperatures. Analyses of gene expression in wild species immediately following initiation of such stresses would greatly extend our understanding of the biochemistry of resistance vs. susceptibility, tolerance vs. intolerance and responsiveness vs. nonresponsiveness among plant genotypes.

CONCLUSIONS

Evolution has resulted in a fantastic array of adaptations that function to moderate the biochemical effects of harsh environments. Many amazing examples occur within the environmental extremes of our terrestrial and aquatic worlds. The structural and physiological mechanisms of such adaptations have largely been described, yet little is known at the molecular level. It is at this molecular ecological interface, that recently developed biotechnological methodologies could make substantial contributions.

As physiological ecology enhanced ecological theory, so also will the advent of molecular ecology. Already monoclonal antibodies are being produced to study the biochemical stress response of plants to disease infestations. Such antibodies could be developed to probe a variety of ecological stresses. Plant infestation is also being studied at the level of differential mRNA synthesis and gene expression. Thus plant pathology is rapidly gaining a molecular basis. Such technologies coupled with others, such as the ability to precisely define plant genomes using RFLP's and to isolate genes by transposon tagging, promise plant biologists a menu of highly specific diagnostic, therapeutic and eventually even recreative scientific research.

REFERENCES

Baulcombe, D. C. 1987. The use of recombinant DNA techniques in the production of virus resistant plants. In: Day, P. S. ed. British Crop Protection Council, Biotechnology and Crop Improvement and Protection Symposium: Proceedings; 1986 March 24-26; Churchill College, Cambridge, England; BCPC Publications: 13-19.

Beckmann, J. S.; Soller, M. 1986. Restriction fragment length polymorphisms and genetic improvement of agricultural species. Euphytica 35:111-124.

Bernatzky, R.; Tanksley, S. D. 1986a. Majority of random cDNA clones correspond to single loci in the tomato genome. Mol. Gen. Genet. 203:8-14.

Bernatzky, R.; Tanksley, S. D. 1986b. Using molecular markers to analyze genome organization and evolution. 7th Intn. Cong. Plant Tis. Cell Cult., Univ. Minn, Abs. 307 p.

Cocking, E. C.; Davey, M. R. 1987. Gene transfer in cereals. Science 236:1259-1262.

Collinge, D. B.; Milligan D. E.; Dow, J. M.; Scofield, G.; Daniels, M. J. 1987. Gene expression in *Brassica campestris* showing a hypersensitive response to the incompatible pathogen *Xanthomonas campestris* pv. *vitians*. Plant Mol. Biol. 8:405-414.

Doring, H.P.; Starlinger P. 1986. Molecular genetics of transposable elements in plants. Ann. Rev. Genet. 20:175-200.

Dutta, S. K. 1986a. DNA systematics, Vol. I Evolution. CRC Press, Inc., Boca Raton, Florida.

Dutta, S. K. 1986b. DNA Systematics, Vol. II Plants. CRC Press, Inc., Boca Raton, Florida.

Eberle, J.; Arnscheidt, A.; Klix, D; Weiler, E. W. B. 1986. Monoclonal antibodies to plant growth regulators III. Zeatinriboside and Dihydrozeatinriboside. Plant Physiol. 81:516-521.

Edwards, M. S.; Stuber, C. W.; Wendel, J. F. 1987. Molecular-marker-facilitated investigations of quantitative-trait loci in maize. I. Numbers, genomic distribution and types of gene action. Genetics 116:113-125.

Esnault, R.; Chibbar, R. N.; Lee, D.; van Huystee, R. B. 1987. Early differences in production of mRNAs for phenylalanine ammonia-lyase and chalcone synthase in resistant and susceptible cultivars of soybean inoculated with *Phytophthora megasperma* f. sp. *glycinea*. Physiol. Mol. Plant Path. 30:293-297.

Fitter, M. S.; Norman, P. M.; Hahn, M. G.; Wingate, V. P. M.; Lamb, C. J. 1987. Identification of somatic hybrids in plant protoplast fusions with monoclonal antibodies to plasma-membrane antigens. Planta 170:49-54.

Gamble, H. R. 1986. Application of hybridoma technology to problems in the agricultural sciences. Beltsville Symposia X. "Biotechnology for solving agricultural problems." May 5-9, 1985: 39-58.

Gendloff, E. H.; Pestka, J. J.; Dixon, D. E.; Hart, L. P. 1987. Production of a monoclonal antibody to T-2 toxin with strong cross-reactivity to T-2 metabolites. Phytopathology 77:57-59.

Goodman, R. M.; Hauptli H.; Crossway, A.; Knauf, Vic C. 1987. Gene transfer in crop improvement. Science 236:48-54.

Grief, C.; O'Neil, M. A.; Shaw, P. J. 1987. The zygote cell wall of *Chlamydomonas reinhardii*: a structural, chemical and immunological approach. Planta 170:433-445.

Hainfeld, J. F. 1987. A small gold-conjugated antibody label: improved resolution for electron microscopy. Science 236:450-453.

Helentjaris, T.; King, G.; Slocum, M.; Siedenstrang, C.; Wegman, S. 1985. Restriction fragment polymorphisms as probes for plant diversity and their development as tools for applied plant breeding. Plant Mol. Biol. 5:109-118.

Helentjaris, T.; Slocum, M.; Wright, S.; Schaefer, A.; Nienhuis, J. 1986. Construction of genetic linkage maps in maize and tomato using restriction fragment length polymorphisms. Theor. Appl. Genet. 72:761-769.

Hess, C. E. 1987. Agricultural Biotechnology - Strategies for National Competitiveness. National Academy Press, Washington, D. C.

Homan, W. L.; van Kalshoven, H.; Kolk, A. H. J.; Musgrave, A.; Schuring, F.; van den Ende, H. 1987. Monoclonal antibodies to surface glycoconjugates in Chlamydomonas eugametos recognize strain-specific O-methyl sugars. Planta 170: 328-335.

Ida, S. 1987. Immunological comparisons of ferredoxin-nitrite reductase from higher plants. Plant Science 49:111-116.

Knox, J. P.; Beale, M. H.; Butcher, G. W.; MacMillan, J. 1987. Preparation and characterization of monoclonal antibodies which recognize different gibberellin epitopes. Planta 170: 86-91.

Keen, N. T. 1986. Novel approaches to improving disease resistance in plants. In: Augustine, P. C.; Danforth, H. D.; Bakst, M. R. eds. Beltsville Symposia X, Biotechnology for Solving Agricultural Problems: Proceedings; 1985 May 5-9, 1985; Beltsville, Maryland: 223-236.

Leach, J. E.; Clafin, L. E. 1987. Dot-immunobinding assay for detecting Xanthomonas campestris pv. holcicola in sorghum. 1987. Plant Dis. 71:31-33.

Lin, C. P.; Chen, T. A.; Wells, J. M.; van der Zwet, T. 1987. Identification and detection of Erwinia amylovora with monoclonal antibodies. Phytopathology 77:376-380.

Mertens, R.; Eberle, J.; Arnscheidt, A.; Ledebur, A.; Weiler, E. W. 1985. Monoclonal antibodies to plant growth regulators. II. Indole-3-acetic acid. Planta 166:389-393.

Nevers, P.; Shepherd, N.; Saedler, H. 1985. Plant transposable elements. Adv. Bot. Res. 12: 102-203.

Nienhuis, J.; Helentjaris, T.; Slocum,M.; Ruggero, B.; Schaefer, A. 1987. Restriction fragment length polymorphism analysis of loci associated with insect resistance in tomato. Crop Sci. 27:979-803.

Osborn, T. C.; Alexander, D. C.; Fobes, J.F. 1987. Identification of restriction fragment length polymorphisms linked to genes controlling soluble solids content in tomato fruit. Theor. Appl. Genet. 73:350-356.

Phillips, A. L.; Parry, M. A. J.; Gutteridge, S. 1986. Alternation of the activity of ribulose-1,5-bisphosphate carboxylase through manipulation of its structure and regulation. In: Day, P. S. ed. British Crop Protection Council, Biotechnology and Crop Improvement and Protection Symposium: Proceedings; 1986 March 24-26; Churchill College, Cambridge, England, BCPC Publications: 61-68.

Potrykus, I.; Saul, M. W.; Shillito, R. D.; Paszkowski, J. 1986. Techniques for transferring genes into plants. In: Day, P. S. ed. British Crop Protection Council, Biotechnology and Crop Improvement and Protection Symposium: Proceedings; 1986 March 24-26; Churchill College, Cambridge, England; BCPC Publications: 21-28.

Raikhel, N. V.; Pratt, L. H. 1987. Wheat germ agglutinin accumulation in coleoptiles of different genotypes of wheat. Localization by monoclonal antibodies. Plant Cell Rep. 6: 146-149.

Raikhel, N. V.; Hughes, D. W.; Galau, G. A. 1986. An enzyme-immunoassay for quantitative analysis of abscisic acid in wheat. In: Fox, E. and Jacobs, M. ed. Molecular Biology of Plant Growth Control. Alan R. Liss, New York: 197-207.

Rose, D. G.; McCarra, S.; Mitchell D. H. 1987. Diagnosis of potato virus Y^N: a comparison between polyclonal and monoclonal antibodies and a biological assay. Plant Path. 36:95-99

Schwarz, H.; Schneider, H. A. W. 1987. Immunological assay of photochrome in small sections of roots and other organs of maize (Zea mays L.) seedlings. Planta 170:152-160.

Sherwood, J. L. 1987. Comparison of a filter paper immunobinding assay, western blotting and an enzyme linked immunosorbent assay for the detection of wheat streak mosaic virus. 1987. J. Phytopathology 118:68-75.

Silberman, L. G.; Datta, N.; Hopps, P.; Roux, S. J. 1985. Characterization of monoclonal antibodies to oat phytochrome by competitive radioimmunoassays and comparative immunoblots of phytochrome peptides. Arch. Biochem. Biophys. 236:150-158.

Smart, C. C.; Amrhein, N. 1987. Ultrastructural localisation by protein A-gold immunocytochemistry of 5-enolpyruvylshikimic acid 3-phosphate synthase in a plant cell culture which overproduces the enzyme. Planta 170: 1-6.

Smith, L. M.; Sabnis, D. D.; Johnson, R. P. C. 1987. Immunocytochemical localisation of phloem lectin from Cucurbita maxima using peroxidase and colloidal-gold labels. Planta 170:461-470.

Soller, M.; Beckmann, J. S. 1983. Genetic polymorphism in varietal identification and genetic improvement. Theor. Appl. Genet. 67:25-33.

Staub, J. E.; Fredrick, L.; Marty T. C. 1987. Electrophoretic variation in cross-compatible wild diploid species of Cucumis. Can. J. Bot. 65:792-798

Stuber, C. W.; Edwards, M. D.; Wendel, J. F. 1987. Molecular marker-facilitated investigations of quantitative trait loci in maize. II. Factors influencing yield and its component traits. Crop Sci. 27:639-648.

Tanksley, S. D.; Orton, T. T. 1983a. Isozymes in plant genetics and breeding, Part A. Elsevier, New York.

Tanksley, S. D.; Orton T. T. 1983b. Isozymes in plant genetics and breeding. Part B. Elsevier, New York.

Trione, E. J.; Banowetz, G. M.; Krygier, B. B.; Kathrein, J. M.; Sayavedra-Soto, L. 1987. A quantitative fluorescence enzymes immunoassay for plant cytokinins. Analyt. Biochem. 162: 1-8.

Trione, E. J.; Krygier, B. B.; Banowetz, G. M.; Kathrein, J. M. 1985. The development of monoclonal antibodies against the cytokinin zeatin riboside. J. Plant Growth Regul. 4: 101-109.

Yuen, G. Y.; Alvarez, A. M. Benedict, A. A.; Trotter, K. J. 1987. Use of monoclonal antibodies to monitor the dissemination of Xanthomonas campestris pv. campestris. Phytopathology 77:366-370.

Vallejos, C. E.; Tanksley, S. D.; Bernatzky, R. 1986. Localization in the tomato genome of DNA restriction fragments containing sequences homologous to the rRNA (45S), the major chlorophyll A/B binding polypeptide and the ribulose bisphosphate carboxylase genes. Genetics 112:93-105.

Vaughn, K. C. 1987. Two immunological approaches to the detection of ribulose 1,5-bisphosphate carboxylase in guard cell chloroplasts. Plant Physiol. 84:188-196.

Vershinin, A. V.; Salina, E. A.; Svitashev, S. K.; Shumny, V. K. 1987. The occurrence of Ds-like sequences in cereal genomes. 1987. Theor. Appl. Genet. 73:428-432.

Wienand, V. 1986. Transposon mutagenesis and its role in gene isolation. 1986 BCPC Mono. No. 39 Biotechnology and Crop Improvement and Protection. In: Day, P. S. ed. British Crop Protection Council, Biotechnology and Crop Improvement and Protection Symposium: Proceedings; 1986 March 24-26; Churchill College, Cambridge, England; BCPC Publications: 29-32.

ORGANOGENESIS AND SHOOT-TIP MULTIPLICATION FROM TISSUE CULTURES OF ATRIPLEX SPECIES

Jerry R. Barrow

ABSTRACT: Roots and shoots were successfully grown from callus cultures of Atriplex canescens and A. griffithsii in some experiments. Attempts to replicate organogenesis in callus or liquid cultures from these species and in A. acanthocarpa, A. confertifolia, and A. polycarpa were unsuccessful, indicating that specific genetic or cultural requirements were necessary for induction. Shoot-tips were multiplied rapidly after two months in culture from diploid (2x), tetraploid (4x), and hexaploid (6x), plants and from three different collections of 4x populations. Shoot-tip multiplication is a promising method of mass propagation of specific genotypes of Atriplex species.

INTRODUCTION

Atriplex species native to the more arid regions of western North America are a valuable component of rangeland for forage, cover, and revegetation of disturbed sites. They may potentially replace undesirable species or be used in marginal agricultural areas to provide forage with minimal or no irrigation. These native plants possess high genetic variability (McArthur and others 1983) and a remarkable ability to survive under extreme conditions. Therefore, they may be used as model systems to study stress tolerance and other survival mechanisms. If survival mechanisms can be identified and the corresponding genes isolated and transferred--using recombinant gene transfer technology--to other economically important plant species, then these other native plants would potentially be a resource of unique genes for stress tolerance and other useful traits.

Plant regeneration and in vitro propagation methods have been developed for a number of agriculturally important plants including agronomic plants, ornamentals, and trees (Conger 1980). By modifying methods, increasing numbers of plants are successfully being cultured. Norma Trolinda (personal communication) successfully regenerated plants from a collection of A. canescens, native to the Lubbock, Texas area, but was unsuccessful in regenerating plants from other A. canescens collections. Wochok and Sluis (1980) reported a method of shoot tip multiplication in A. canescens, with some spontaneous rooting. Apparently they were not successful in transferring rooted shoots to soil.

In the current research program, plant tissue culture methods were applied to Atriplex species to develop new approaches to shrub research. Cell cultures are used to study cellular responses to environmental stress and to develop unique selection methods. Plant regeneration capability would allow the recovery of valuable genes identified from in vitro experiments and allow their expression in whole plants. Shoot multiplication is a method of mass propagating specific genotypes for genetic studies, plant improvement, and other research approaches.

MATERIALS AND METHODS

In preliminary studies, embryos from two species, A. canescens and A. griffithsii, were removed from fruits and sterilized 7 min in 95% ETOH, then 20 min in 40% commercial bleach (2% sodium hypochlorite), and rinsed 30 min in sterile distilled water. They were germinated on 1/10 concentration BDS medium, which was modified from the B5 medium of Gamborg and others (1968), by Dunstan and Short (1977) with no growth regulators (table 1). Hypocotyls 1/2 to 1 cm long from A. griffithsii were plated on L2 medium of Phillips and Collins (1978) and labeled L2-C-init medium (table 2) to initiate callus. Callus was subcultured at approximately 1 cm in diameter, on the same initiation medium, and then subcultured monthly on L2-C-prlf to increase the quantity of the tissue. After 2 subcultures, the callus was transferred to L2-C-reg medium to induce regeneration. A similar sequence was used to culture A. canescens on the BDS series of media.

Callus cultures from five species, A. acanthocarpa, A. canescens, A. confertifolia, A. griffithsii, and A. polycarpa, were generated in the above manner and cultured on the L2 media series to determine their regeneration capacity. Liquid cultures were developed by culturing callus pieces in liquid L2-C-prlf medium on a rotary shaker under 16 h light, rotating at approximately 60 rpm.

Shoot-tip cultures were initiated from three cytotypes, diploid (2x), tetraploid (4x), and hexaploid (6x), plants described by Dunford (1984); and from 4x plants from three locations, one in west Texas, a high elevation site in New Mexico, and an arid site in southeastern Arizona.

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Jerry R. Barrow is Research Geneticist, Jornada Experimental Range, Agriculture Research Service, U.S. Department of Agriculture, New Mexico State University, Las Cruces, NM.

Table 1--Nutrient concentrations of culture media

	Final concentration (mM)	
	BDS	L2
Major salts		
$CaCl_2$	0.00	4.10
KNO_3	23.20	20.77
$KH_2PO_4.H_2O$	0.00	2.39
$NH_4H_2PO_4$	2.00	0.00
$Na_4H_2PO_4.H_2O$	1.25	0.62
$(NH_4)SO_4$	1.01	0.00
$MgSO_4.7H_2O$	1.00	1.76
NH_4NO_3	4.00	12.50
$FeSO_4 7H_2O$.EDTA	0.09	0.09
	Final concentration (µM)	
	BDS	L2
Minor salts		
H_3BO_3	48.00	80.85
KI	2.20	6.02
$MnSO_4.H_2O$	29.60	88.75
$ZnSO_4,7H_2O$	3.50	17.40
$CuSO_4.5H_2O$	0.08	0.40
$Na_2MoO_4 2H_2O$	0.50	1.66
$CoCl_2.6H_2O$	0.05	0.42
	Final concentration (mM)	
	BDS	L2
Vitamins		
Inositol	0.55	1.39
Thiamine.HCL	0.03	0.006
Pyridoxine.HCL	0.005	0.024
Nicotinic Acid	0.008	0.000
Other Additives		
Sucrose	30.0 g per liter	
Agar	6.0 g per liter	
pH adjusted to 5.6		

For multiplication, growing points approximately 1 to 2 mm were excised from the growing tip of germinating seedlings and cultured base down in BDS-G-Sm (table 2). Lateral shoots from mature plants were also collected, sterilized 20 minutes in 40% commercial bleach and rinsed in sterile distilled water. Then, 3 to 5 mm shoot-tips were excised and plated on BDS-G-Sm medium in 100 mm Petri dishes.

To induce rooting, individual shoots approximately 1 cm long, were excised from the shoot multiplication cultures and placed base down on the BDS-G-Rm medium and cultured in the growth chamber. All tissue cultures were incubated at 25 °C in a growth chamber with a 12 h light period.

RESULTS AND DISCUSSION

A total of 22 shoots developed from callus of *A. canescens* and 32 shoots from callus of *A. griffithsii* in the initial experiment, as a response to decreasing picloram from 0.1 to 0.025 mg per litter and increasing 6, bensyladenine (6BA) to as high as 4.0 mg per liter in the regeneration medium. Because of the difficulty of maintaining *A. canescens* callus on BDS medium, all species were grown in L2 medium in subsequent experiments. Callus formed readily from both species and grew well in subcultures. Cell suspension cultures were readily initiated in liquid media from the callus cultures. Subsequent attempts to produce shoots on previously successful or modified media were not successful, indicating a genetic requirement or a specific nutritional requirement for organogenesis to occur.

Table 2--Growth regulator concentration of media

Media	Pic.(mg/l)	6,BA(mg/l)	GA	IAA
BDS-C-init	0.75	1.5	0	0
BDS-C-prlf	0.25	1.5	0	0
BDS-C-reg	0.00	0-4.0	0	0
BDS-G-Sm	0.00	0.5	4.0	0
BDS-G-Rm	0.00	0.0	0.1	0.5
L2-C-init	0.20	0.1	0	0
L2-C-prlf	0.10	1.5	0	0
L2-C-reg	0.025	1.0-2.0	0	0

Shoot multiplication experiments were generally successful independent of the cytotype or the collection used. This technique promises to be a useful method of replicating plants of a specific genotype. Tetraploid plants were the most responsive to shoot-tip multiplication, with several collections having shoots increasing 4 times every 10 days. This rate allows replicating large numbers of plants from a given selection quickly. Shoot cultures, at times, developed roots which were not specifically attached to shoots and they were not successfully transferred to soil. Specific rooting was initiated by excising single shoots from multiplication cultures and transferring them to a 1/2 strength rooting medium, BDS-G-Rm (table 2). After two weeks, roots began to develop at the base of the shoots. Rooted shoots were transplanted into peat pellets and covered with a beaker where they grew and were subsequently transplanted into soil where they were grown to maturity.

REFERENCES

Conger, B. V. 1980. Cloning agricultural plants via *in vitro* techniques. Boca Raton, FL: CRC Press.

Dunford, M. P. 1984. Cytotype distribution of *Atriplex canescens* (Chenopodiaceae) of southern New Mexico and adjacent Texas. Southwest Nat. 29: 223-238.

Dunstan, D. I.; Short, K. C. 1977. Improved growth of tissue cultures of the onion, *Allium cepa*. Physiol. Plant. 41: 70-72.

Gamborg, O. L.; Miller, R. A.; Ojima, K. 1968. Nutrient requirements of suspension cultures of soybean root cells. Exp. Cell Res. 50: 151-158.

Phillips, G. C.; Collins, G. B. 1979. *In vitro* tissue culture of selected legumes and plant regeneration from callus cultures of red clover. Crop. Sci. 19: 59-64.

McArthur, E. D.; Stevens, R.; Blauer, A. C. 1983. Growth performance comparisons among 18 accessions of fourwing saltbush *Atriplex canescens* at two sites in central Utah. J. Range Manage. 36: 78-81.

Trolinder, N. 1987. [Personal communication]. Lubbock, TX: Texas Tech University.

Wochok, Z. S.; Sluis, C. J. 1980. Gibberellic acid promotes *Atriplex* shoot multiplication and elongation. Plant Sci. Lett. 17: 363-369.

RESPONSES OF CALLUS CULTURES, MICROSHOOT CULTURES, AND WHOLE PLANTS OF THE HALOPHYTE, *ATRIPLEX CANESCENS* VAR. *GIGANTEA* TO EXOGENOUS NaCl

Eve Syrkin Wurtele

ABSTRACT: Plants, *in vitro* microshoots and calli of *Atriplex canescens* var. *gigantea* were continuously grown in media containing various levels of NaCl. Plants could grow in 1 M NaCl, however, microshoots and calli only grew on up to 100 and 300 M NaCl, respectively. The water and osmotic potentials of plants, microshoots, and calli decreased with exposure to decreased external water potential. However, the plants maintained water potentials significantly greater than the external water potential at all external NaCl concentrations. Microshoot water potentials were somewhat lower and calli water potentials were similar to the external media. In plants and calli, the turgor decreased with decreasing external water potential. However, the turgor of microshoots increased as the external water potential decreased. Cells of microshoots, but not plant or calli cells, responded to increased exogenous NaCl by expansion and increased trichome formation. In microshoots and calli, there was a correlation between the endogenous Na+ concentrations and survival, while plants survived with somewhat higher leaf internal Na+ concentrations. One explanation of this may be the apparent absence of functional trichomes on microshoots (or calli). Ion accumulation in cells of *A. canescens* was higher than that previously described for other cells, indicating a strong cellular basis for ion uptake. Mutagenesis of microshoots with ethylmethyl sulfonimide has resulted in a population of microshoots with increased salt tolerance. The mechanism(s) of this salt tolerance, and the salt tolerance of the corresponding plants, has yet to be determined.

INTRODUCTION

The genus *Atriplex* includes some very salt tolerant species, and biotypes from several of these species have great promise for utilization for biomass production, forage, and reclamation in arid and semiarid regions (Goodin and McKell 1971; McKell 1983), and as a source of triterpenoid saponins (Wurtele and others 1987). Within the genus *Atriplex*, a variety of mechanisms exist by which different species adapt to saline environments (Mozafar and Goodin 1970). Some mechanisms of salt tolerance operate at the cellular level, such as compartmentalization of Na+ in the vacuole with a concomitant accumulation of nontoxic organic osmotic agents in the cytoplasm (Storey and others 1983) and increased succulence (Sharma 1982). Other mechanisms require higher levels of tissue organization, for example, compartmentation of salts in specialized cells such as trichomes (Mozafar and Goodin 1970), or substitution of K+ for Na+ at the root (Norton 1984).

By examining the ways in which whole plants, microshoots, and callus cultures respond to external NaCl we can gain a better understanding of the cellular and physiological mechanisms by which plants can maintain growth in highly saline environments. Such evaluations can also increase our ability to select various types of salt tolerance *in vitro*, and can facilitate the cloning of genes which play a critical role in salt tolerance.

Although the *A. canescens* var. *gigantea* (*gigas*) biotype is a prime candidate as a biomass species because of its rapid growth (Stutz and others 1975; McKell 1983), its salt tolerance has not been investigated. In this report we describe and compare the effects of external NaCl on the growth morphology, succulence, water relations, and K+ and Na+ content of callus cultures, microshoot cultures, and whole plants of *A. canescens* var. *gigantea*.

MATERIALS AND METHODS

Plants

Plants of *Atriplex canescens* var. *gigantea* (Welsh and Stutz 1984) = the *gigas* form of Stutz and others (1979) were originally obtained from cuttings from a single plant (genotype 9 female). Those plants were grown in the greenhouse as previously described (Wurtele and others 1987) and were utilized as the explant source for microshoot and callus cultures, and for obtaining cuttings as described below.

Cuttings (8 to 10 cm long) were obtained from these plants, and were rooted in tube containers (5 cm diameter, 25 cm length) which were filled with sand. After roots were established (3-4 weeks), the tubes were immersed in aqueous solutions containing Hoagland's macro- and micro-nutrients (Hoagland and Arnon 1950) with varying concentrations of NaCl. The solutions were changed at monthly intervals.

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Eve Syrkin Wurtele is Cell Biologist, NPI, 417 Wakara Way, Salt Lake City, UT 84108

Microshoot Culture

Apical buds and axillary buds were used as the explant source of shoot multiplication, by a modification of a previously described method (Wurtele and others 1987). Sterilized lateral bud explants were aseptically placed in a culture tube containing Murashige and Skoog salts and vitamins (Murashige and Skoog 1962), 3% sucrose, and 0.6% Difco agar (basal medium), supplemented with 1 mg l^{-1} benzyladenine (BA). The shoots were grown in a daily cycle of 16 h of fluorescent light in cycles of 27 ± 2°C 8 h of dark at 25 ± 2°C.

Shoot clumps were subcultured at monthly intervals. For each subculture, the tops were removed from shoots which were over 2 cm in height. Shoot clumps were then divided into pieces each consisting of three or four shoots, attached at their base. These pieces were transferred to fresh medium and grown under the conditions described above.

Three or more months after initiation, microshoots were placed in basal medium with 1 mg l^{-1} BA and added NaCl. These microshoots were grown and subcultured at monthly intervals as described above.

Callus Culture

Leaves that were almost fully expanded were washed in tap water for 2 h, surface sterilized for 10 min in 1% NaOCl, and rinsed three times in sterile distilled water, and utilized as the explant source for callus cultures. Explants were placed abaxial side down onto the basal culture medium supplemented with 0.5 mg l^{-1} 2,4-dichlorophenoxyacetic acid (2,4-D). Two months after initiation, calli were divided into pieces of 0.4 to 0.6 g fresh weight and subcultured onto fresh medium. Calli were grown under cycles of 16 h of fluorescent lights at 27 ± 2°C, and 8 h of dark at 25 ± 2°C.

Growth Measurements

Fresh weights were determined for plant material from 10 replicate jars, each jar containing three explants right after subculture. Half of the explants were dried in a drying oven for 48 h and individual dry weight determinations were obtained. The remaining half were allowed to remain on the medium under the growth conditions described previously. After 30 days, fresh and dry weight determinations were made for the remaining explants. All experiments were repeated at least once.

Water Relations

Water potentials of plants were measured with a Scholander-type pressure chamber (PMS Instrument Co., Corvallis, OR). Shoots were collected at 10 a.m. and pressure-volume curves were generated (Scholander and others 1965; Tyree and Hammel 1972) from which the osmotic potential and turgor were calculated.

At the time of subculture, the water potentials of the microshoot and callus cultures were measured with C-30-Sf sample chambers connected to an HP-115 Microprocessor Controlled Water Potential Data System (Wescor, Inc.; Logan, UT) in the dew point (hydrometric) mode. Osmotic potentials of calli and microshoots were measured by the same method after the same tissue was frozen in liquid nitrogen and then thawed. Turgor was calculated as the difference between the water and osmotic potential. All experiments were repeated at least once.

Analysis of Na+ and K+

Endogenous concentrations of Na+ and K+ were determined by atomic absorption spectrophotometry of oven-dried plant parts (0.1 to 0.25 g dry weight), digested with concentrated nicric acid (Haulin and Soltanpour 1980).

Scanning Electron Microscopy

Scanning electron microscopy (SEM) was performed on plant material growing in 0, 100, 150, or 500 mM NaCl media. Plant material was fixed in 1% aqueous osmium tetroxide, and then coated with additional osmium tetroxide by the OTO method of Kelly and others (1973). The specimens were dehydrated in a graded ethanol series and dried from CO_2 by the critical point method (Anderson 1951). Samples were sputter-coated with gold, and examined at 10 KeV or at 15 KeV in a Hitachi S-450 SEM. Several samples of each type of plant material were observed and the micrographs represent typical samples.

Selection of Material for Analysis

All material analyzed was from plants or cultures grown for 4 to 6 months (with subcultures) on medium containing a specific concentration of added NaCl. Leaves which were almost fully expanded were utilized for all studies of plant leaves.

RESULTS AND DISCUSSION

Growth

The growth rates of plants, microshoots, and calli grown in the different concentrations of added NaCl were determined.

The shoots of plants grown in all levels of NaCl increased in height (table 1). The growth rate was maximal between 0 to 100 mM NaCl and was lowest at 1 M NaCl. Plants grown in all concentrations of NaCl appeared morphologically similar. In contrast, though, the microshoots grew vigorously on media containing no added NaCl and even more vigorously on 50 mM NaCl, growth on medium containing 100 mM NaCl, expressed as an increase in fresh weight, was very low (table 1). The microshoots which were subcultured on 300 mM

Table 1--The increase in growth of *A. canescens* var. *gigantea* grown in media containing additions of NaCl

	NaCl(mM)	% increase/30 days
Shoots of whole plants[1]	0	154
	100	145
	500	133
	750	131
	1000	109
Microshoots[2]	0	1100
	50	960
	100	260
	300	(dead)
Callus Cells[2]	0	496
	50	607
	150	432
	300	169
	500	(dead)

[1] Increase in height, results are means of three replicates.

[2] Increase in weight, results are means of five replicates.

NaCl for 3 months did not survive (data not shown). Microshoots grown without added NaCl were dark green and appeared healthy. Those grown on 50 mM NaCl were lighter green and the leaves showed increased succulence. The microshoots grown on 100 mM NaCl were light green and vitreous, with very succulent leaves.

Callus growth occurred on media containing up to 300 mM NaCl (table 1). The relative growth rate, based on fresh and dry weight, was greatest for calli growing on 50 mM NaCl. The relative growth rate of calli was similar on 0 and 150 mM NaCl. Growth was considerably reduced for callus exposed to 300 mM NaCl. Calli grown on 0 and 50 mM NaCl were bright green; calli grown on 150 mM NaCl were either green or greenish-white; calli grown on 300 mM NaCl were whitish-brown. The majority of cells grown on 0 to 150 mM NaCl were small spherical cells (30 to 50 m diameter).

Correlations between the level of salt tolerance of callus cultures and in whole plants have been found for several species (Tal and others 1978; Orton 1980; Smith and McComb 1981), including the halophytes, *Suaeda martima* (Von Hedenstrom and Breckle 1974), *Spartina spicata* (Warren and others 1985), and *Distichlis spicata* (Daines and Gould 1985). However, no such correlation has been found for *Suaeda australis* (Smith and McComb 1981), *Salicornia herbacea* (Strogonov 1973), or *A. undulata* (Smith and McComb 1981).

For both microshoots and calli of *A. canescens*, growth was greater at 50 mM than at 0 mM NaCl (growth in 50 mM NaCl was not examined for whole plants, although the growth of plants of several species of *Atriplex* is stimulated at 50 mM NaCl [Jeschke and Stelter 1983]). Thus, a small amount of NaCl added to the media actually stimulates growth both *in vivo* and *in vitro*. Such a growth increase at 50 mM NaCl was not found for calli of *A. undulata* (Smith and McComb 1981) growing in a similar medium and in a similar environment.

Water Relations in Response to Exogenous NaCl

The water potential of shoots from *A. canescens* var. *gigantea* plants grown in 750 mM NaCl was over threefold lower than in 0 mM NaCl; osmotic potential was twofold lower at 750 mM NaCl than at 0 mM NaCl (fig. 1). This is similar to the water and osmotic potentials of shoots from plants of several *Atriplex* spp. which decrease as plants are grown in soils of decreasing water potential to (e.g. Storey and Jones 1979; Osmond and others 1980; Sharma 1982; Gale and others 1970; Riehl and Ungar 1983). In microshoots and calli of *A. canescens*, growth in higher levels of NaCl similarly resulted in decreased water and osmotic potentials (figs. 2, 3), indicating a cellular basis for these responses.

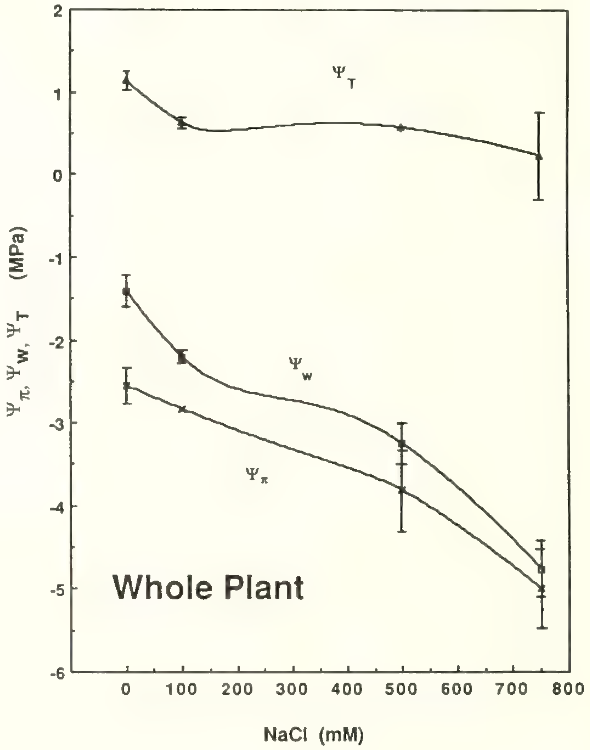

Figure 1--Water potential, osmotic potential, and turgor of plants grown in solutions containing different concentrations of NaCl.

The osmotic potential of the shoots of plants was in all cases lower than that of the microshoots which was lower than that of the callus cells at any given exogenous concentration of NaCl (figs. 1-3). This could be caused by morphological and anatomical differences (such as the presence of

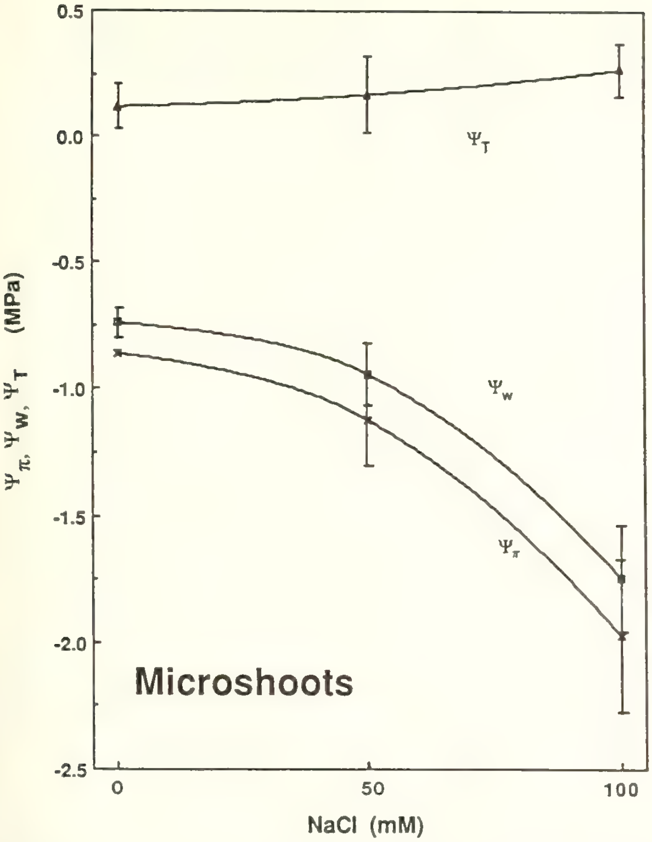

Figure 2--Water potential, osmotic potential, and turgor of microshoots grown on media containing different concentrations of NaCl.

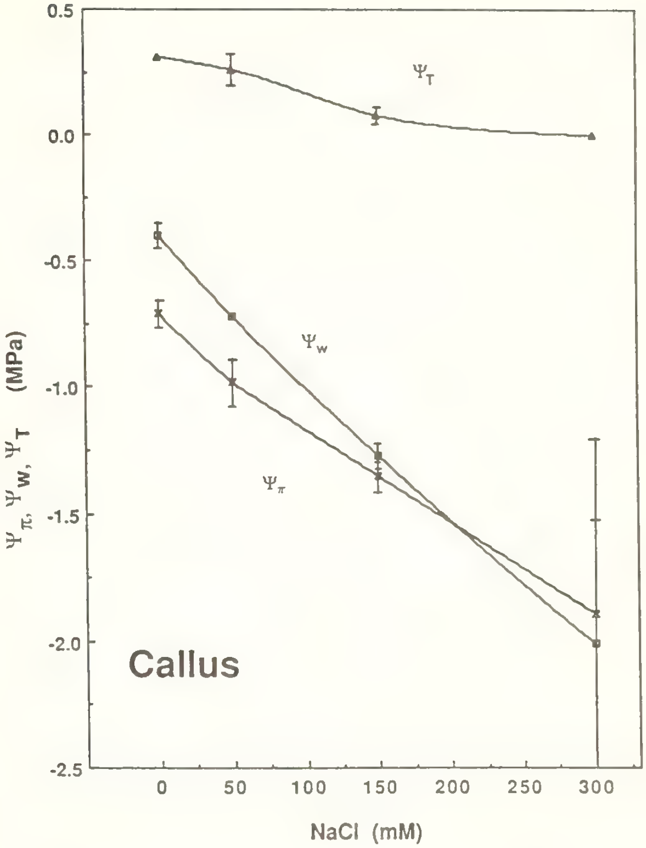

Figure 3--Water potential, osmotic potential, and turgor of callus cells grown on media containing different concentrations of NaCl.

roots or trichomes) which promote greater uptake and accumulation of salt and/or synthesis of organic osmotic agents by the intact plant. Additionally, the lack of differentiated vascular elements in callus tissue probably further restricted uptake of water and salts into callus tissue. The lower osmotic potential of the shoots of plants compared to the microshoots and calli could also have been, in part, a consequence of differences in the ambient environment. The decreased humidity in which the plants were grown could further add to a greater flow of water and dissolved salts into the intact plant.

The shoot turgor decreased for A. canescens plants grown in increasing NaCl, e.g. at 0 mM NaCl the turgor was almost fivefold higher than at 750 mM NaCl. In calli, turgor also decreased with increasing NaCl, from 0.31 MPa at 0 mM NaCl to 0 MPa at 300 mM NaCl. Our results for the turgor of salt-adapted A. canescens var. gigantea callus cells are similar to those which can be calculated from osmotic potential determinations for salt-adapted suspension cells of the halophyte Distichlis spicata (Daines and Gould 1985). Interestingly, this decrease of turgor in cells of these two halophytes grown in high NaCl contrasts to an increase of turgor reported for water-stressed suspension cells of the glycophyte, tobacco (Handa and others 1983).

Unlike the behavior of the shoots of plants and the callus cells, the osmotic potential of the microshoots over-compensated in response to increased NaCl in the media, such that the turgor actually increased with increased salinity of the growth medium. To our knowledge, no other studies have been made of the effect of NaCl on microshoot turgor. Such studies in glycophytes and in other halophytes might help to elucidate the mechanisms of turgor maintenance and osmotic compensation.

Na+ and K+ Content

The accumulation of high levels of Na+ in leaves is a characteristic of successful halophytes growing in high Na+ (Flowers and others 1977; Osmond and others 1980). The concentrations of Na+ and K+ were determined for leaves and roots of plants, leaves of microshoots, and callus of A. canescens var. gigantea grown in various concentrations of NaCl. The K+ content on a dry weight basis was fairly constant in leaves of plants grown in solutions containing a wide range of added NaCl (fig. 4). In contrast, Na+ concentrations increased sharply in plants grown in solutions with higher levels of exogenous NaCl. The Na+ concentration in leaves was about 16-fold higher in plants grown in 500 mM NaCl medium than in plants grown in medium without added NaCl (fig. 5). Up to 12% of the dry weight of A. canescens var. gigantea leaves was due to Na+; this is about 10 times greater than the Na+ content reported for a polyploid A. canescens by

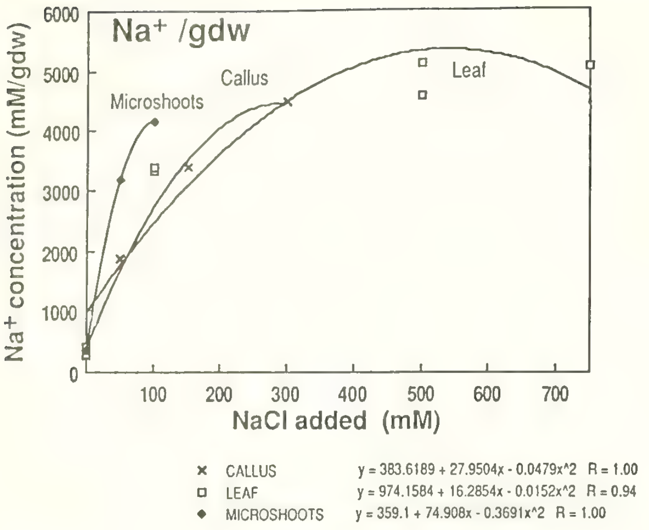

Figure 4--Potassium content of shoots of plants, microshoots, and callus cells grown with different concentrations of NaCl.

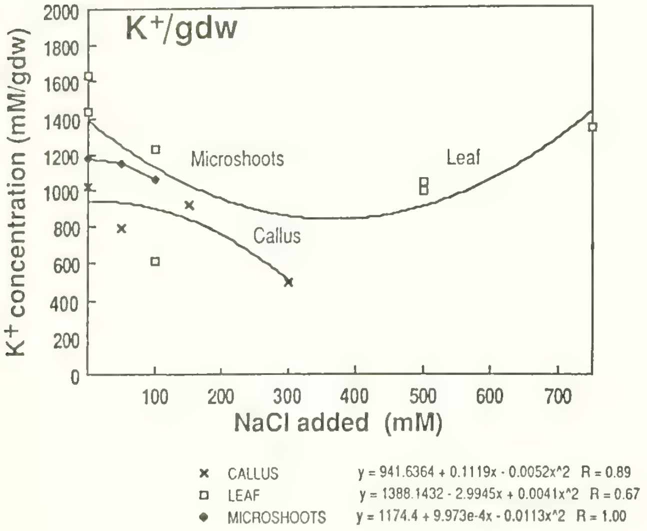

Figure 5--Water potential, osmotic potential and turgor of callus cells grown on media containing different concentrations of NaCl.

Wallace and others (1982). As for several other *Atriplex* genotypes (Mozafar and others 1970; Sharma 1982; Wallace and others 1982; Storey and others 1983), the K+ content of the *A. canescens* var. *gigantea* plants did not change significantly over a wide range of exogenous Na+ concentrations.

The Na+/K+ ratios reported for leaves of different *Atriplex* genotypes grown at a given concentration of NaCl vary widely (e.g. Chatterton and others 1970; Storey and Jones 1979; Osmond and others 1980; Ruess and Wali 1980; Wallace and others 1982). The Na+/K+ ratios for *A. canescens* var. *gigantea*, which ranged from 0.1 for leaves of plants grown in 0 mM NaCl solution to 2 or 3 for leaves of plants grown in higher NaCl concentrations, are similar to those of two biotypes of tetraploid, hydroponically grown *A. canescens* (Norton and others 1984). However, the Na+/K+ ratio for a field grown polyploid *A. canescens* genotype indigenous to a particularly harsh environment (Ruess and Wali 1980) was over 10 times greater than that for *A. canescens* var. *gigantea*. Thus, although accumulation of Na+ is high in *A. canescens* var. *gigantea*, it may be higher still in other *A. canescens* genotypes, i.e. those with greater salt tolerance.

For *A. canescens* var. *gigantea*, the Na+/K+ ratio is similar for calli, microshoots, and leaves of plants grown in the same concentration of NaCl. This similarity of Na+/k+ ratios may indicate that the relative uptake of the Na+ and K+ ions has a broad cellular basis, and is not solely dependent on the presence of roots or of a specific root cell type. These Na+/k+ ratios cannot account for the relatively much greater NaCl tolerance of the *A. canescens* var. *gigantea* plants.

A correlation between the level of salt tolerance in the whole plant and in the callus has been demonstrated for several species (including both glycophytes and halophytes), and the absence of such a correlation has been demonstrated for others (e.g. Dix and Street 1975; Tal 1978; Smith and McComb 1981). Callus cells of *A. canescens* var. *gigantea* showed little salt tolerance compared to that of the whole plants. This is similar to what was reported for *A. canescens* var. *gigantea* (Smith and McComb 1981), although recent observations indicate that callus cultures of at least two other *Atriplex* genotypes may have much higher NaCl tolerance (J. Goodin and J. R. Barrow, personal communication).

The relationship between the salt tolerance and ion uptake for plants and calli has only been examined in a few cases. The Na+ and/or K+ concentrations in NaCl adapted cells of the glycophytes *Nicotiana tabacum* and *Citrus cinensis* (Heyser and Nabors 1981; Ben-Hayyim and Kochba 1983; Lerner and others 1985), the moderately salt tolerant *Medicago sativa* (Croughan and others 1978), and the ahlophyte *Distichlis spicata* (Daines and Gould 1985) have been analyzed previously. The Na+/K+ for the *A. canescens* var. *gigantea* callus cells adapted to a given concentration of NaCl is less than half that of the comparable salt-adapted cells of tobacco. The absolute level of Na+ in *A. canescens* var. *gigantea* cells is about two-to eightfold higher than in tobacco, citrus, alfalfa or *D. spicata* cells, and the concentration of K+ in the *Atriplex* cells is two- to tenfold higher than in tobacco, citrus, or alfalfa cells. Thus, the ionic uptake responses of the halophyte *A. canescens* appear to be quite different from those of tobacco, alfalfa, or *D. spicata*, indicating a species dependent cellular basis for ion uptake, with much higher levels of ion accumulation occurring in *A. canescens*. Furthermore, these data are consistent with the notion that the *Atriplex* cells are able to tolerate higher levels of internal Na+ than can cells of tobacco. Perhaps *A. canescens* var. *gigantea* cells have more efficient mechanisms for subcellular compartmentalization of ions in the vacuole.

Morphology and Succulence

One response associated with growth in high NaCl is increased succulence. For the diployd A. canescens var. gigantea, we found only a 12% to 18% increase in plant leaf succulence. Leaves of plants in 100 to 750 mM NaCl solutions could not be readily distinguished by visual and SEM observations from leaves of plants grown in 0 mM NaCl (fig. 6). There was little or no increase in the diameters of mesophyll or epidermal cells in leaves of NaCl grown A. canescens var. gigantea plants, although such increases have been reported for A. patula (Longstreth and Nobel 1979). Trichome size appeared to be only slightly greater for leaves of NaCl-grown A. canescens var. gigantea than for leaves of plants grown in medium with added NaCl. Therefore, an increase in leaf succulence does not appear to be a major mechanism for NaCl tolerance in the whole plant of A. canescens var. gigantea.

In contrast, the ratio of fresh weight to dry weight of A. canescens var. gigantea NaCl grown microshoots was about twice that of the microshoots grown without added NaCl. Furthermore, leaves of microshoots grown on 100 mM NaCl medium were visibly thicker and larger than their counterparts grown on 0 mM NaCl medium, and displayed a marked increase in the diameter of mesophyll and epidermal cells, but not bundle sheath cells (figs. 7, 8). Increased succulence has been attributed to high Cl levels (Flowers and others 1977); it is possible that Cl uptake differs between plants and microshoots of A. canescens var. gigantea.

Atriplex which use the C3 and C4 photosynthetic pathways have been reported (Osmond and others 1980). Leaves of one biotype of tetraploid A. canescens (Norton and others 1984) appear to have "Kranz anatomy." The leaf cross sections of A. canescens var. gigantea displayed typical "Kranz anatomy: (fig. 8), indicating that this diploid variety is likely also C4.

Few studies have compared the internal leaf anatomy of plants to that of in vitro microshoots, and this is, to our knowledge, the first such study of a C4 plant. Wetzstein and Sommers (1982) demonstrated a marked decrease in the degree of organization of the mesophyll tissues of the microshoot leaf compared to those of the plant leaf for sweet gum. Our examination of Atriplex microshoots indicates a similar decrease in mesophyll organization. Furthermore, the bundle/sheath strands are less developed, and difficult to distinguish from the mesophyll cells. In addition, the mesophyll and epidermal cells of the microshoot leaf are very vacuolate, in sharp contrast to the cytoplasmically dense cells of the plant leaf.

Another difference between leaves of plants and those of microshoots is the presence of a more highly developed cuticle on the plant leaves (Wetzstein and Sommers 1982). It has been hypothesized that the trichomes of A. halimus plants growing in salt do not absorb water despite a large increase in salt content because they are surrounded with a cuticle which is impermeable to water (Mozafar and Goodin 1970). Although we do not have data on cuticle thickness for A. canescens var. gigantea, our observations are consistent with these reports. The trichomes of A. canescens var. gigantea microshoots growing on medium containing added NaCl are greatly expanded in comparison to those of microshoots growing on medium without added NaCl, whereas the trichomes of the corresponding plants are only slightly greater in size.

The number of the microshoot trichomes was much lower than for leaves of plants grown on 0 mM NaCl solution. Also, microshoots grown on 0 mM NaCl medium had a much lower trichome density than microshoots grown on 100 mM NaCl medium. Thus, environment, as well as genetics (Osmond and others 1980), appears to have a great effect on trichome density and morphology.

The callus cells showed a 15% to 20% increase in succulence in response to exogenous NaCl. However, the cell size was similar (fig. 9) with a slightly greater proportion of large cells in the 0 mM NaCl calli.

Interestingly, the callus of A. canescens var. gigantea is somewhat more NaCl-tolerant than is the more organized microshoot. Although the microshoots have trichomes, it is not clear that they function. Cytoplasmic density of the stalk cells has been correlated with functioning trichomes (Kelley and others 1982), and the stalk cells of the microshoot leaf are much less cytoplasmically dense that those of the plant leaf. Perhaps, factors such as high humidity, absence of a cuticle, and/or altered photosynthesis impair trichome function in the microshoot. A toxic concentration of Na+ could, therefore, accumulate in the cytoplasm of the cells of the microshoot causing the low tolerance of the microshoots to external NaCl. Clearly, the increase in leaf succulence observed for the microshoots exposed to NaCl is not sufficient to confer high salt tolerance. The slight increase in succulence of the callus together with a somewhat lower absolute concentration of Na+ and K+ might explain the somewhat greater salt tolerance of the callus compared to that of the microshoot.

Selection of Callus Cells and Microshoots With Increased NaCl Tolerance

Callus cells and microshoots were grown for prolonged period (12-14 mo) in 300 and 100 mM external NaCl, respectively. In no case did an increase in salt tolerance occur, as evidenced by a similar monthly growth rate over a 12-month period. This is somewhat surprising in view of the fact that even cells of many glycophytes such as tobacco (e.g. Dix and Street 1975) develop an increased tolerance to external NaCl. Microshoots also did not increase in NaCl tolerance even after 13 months of selection on NaCl-containing medium.

Microshoots were treated with the mutating agent ethylmethyl sulfonimide (EMS) and allowed to multiply. After a period of 13 months, only

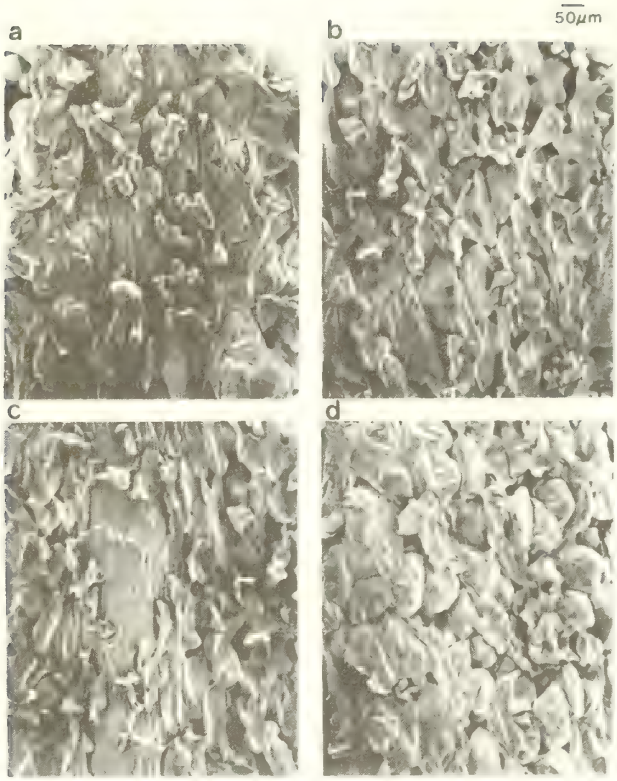

Figure 6--SEM of leaves of plants of *A. canescens* var. *gigantea*. A,B) plants grown without added NaCl; C,D) plants grown with 100 mM added NaCl; A,C) adaxial; B,D) abaxial. Surface views at identical magnifications.

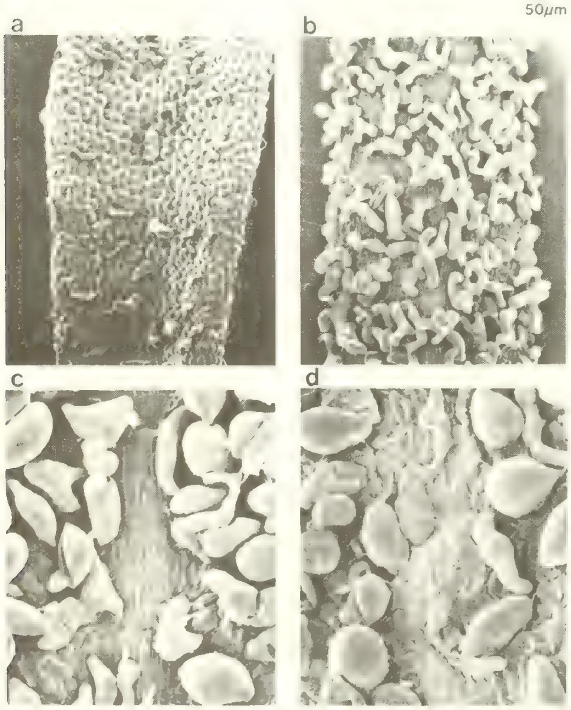

Figure 7--SEM of leaves of microshoots of *A. canescens* var. *gigantea*. A,B) microshoots without added NaCl; C,D), microshoots grown with 100 mM added NaCl; A,C, adaxial; B,D), abaxial. Surface view at identical magnifications.

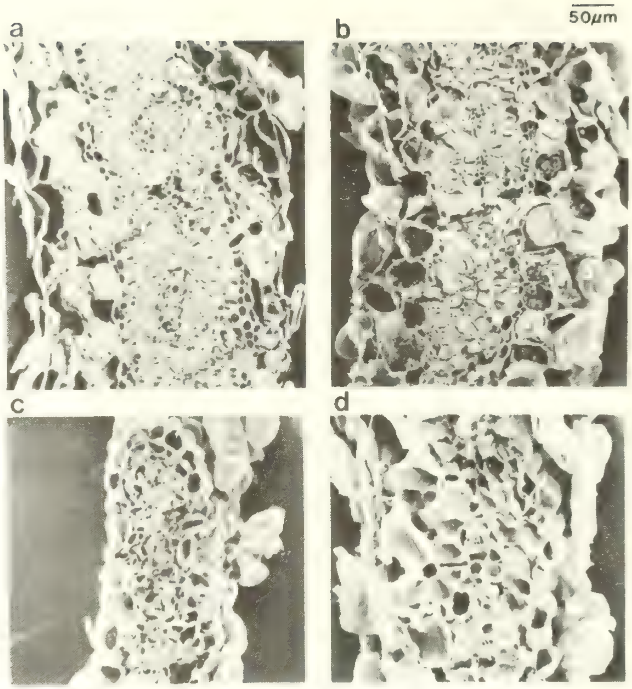

Figure 8--SEM of callus cells of *A. canescens* var. *gigantea*. A,B) callus cells grown with added NaCl; C,D) callus cells grown with 100 mM added NaCl. Surface views at identical magnifications.

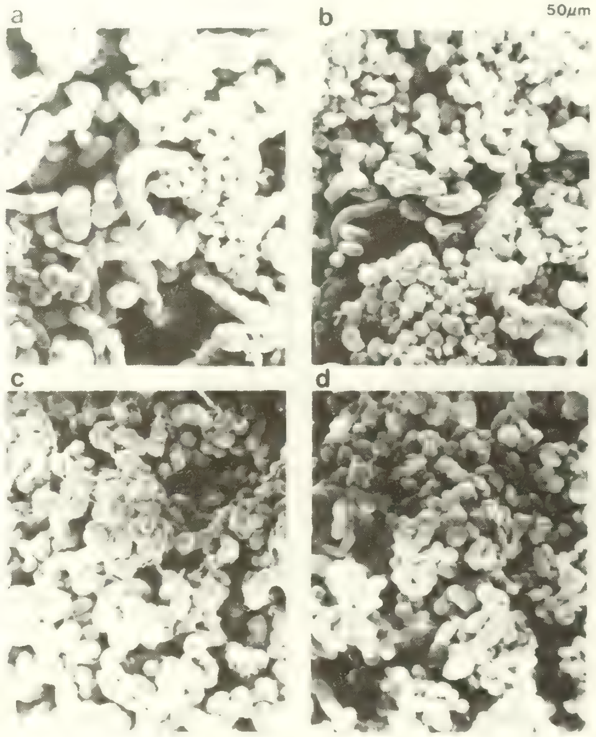

Figure 9--SEM of leaves of plants (a,b); and leaves of microshoots (c,d) of *A. canescens* var. *gigantea*. A,C) grown without added NaCl; B,D) grown with 100 mM NaCl. Cross sectional views at identical magnifications.

Table 2--Multiplication rates for shoots of *A. canescens* var. *gigantea* (genotype 9 female) pretreated with EMS and transferred onto media containing 0, 100, and 300 mM NaCl. Cultures were divided and transferred at monthly intervals

		Transfer			
EMS	NaCl	1	2	3	13
%	mM	Multiplication Rate			
0	0	3.8 ± 1.7	3.3 ± 1.7	3.4 ± 1.9	3.3 ± 1.0
1	0	3.2 ± 1.3	4.3 ± 1.4	2.5 ± 0.8	3.6 ± 1.1
2.5	0	2.8 ± 1.2	3.6 ± 1.5	3.0 ± 0.9	4.1 ± 2.4
0	100	1.2 ± 0.8	2.2 ± 1.0	0.8 ± 0.3	----
1	100	N.D.	1.3 ± 0.6	0	----
2.5	100	N.D.	1.7 ± 1.1	1.9 ± 0.8	1.4 ± 0.7
0	300	N.D.	0	0	----
1	300	N.D.	0.8 ± 0.3	0	----
2.5	300	N.D.	0.5 ± 0.2	0	----

Table 3--Responses of *Atriplex canescens* var. *gigantea* to growth in increased external NaCl

	Shoots of Whole Plants	Microshoots	Callus Cells
Growth	Survive to> 1 M Nacl	Survive to 100 mM NaCl	Survive to 300 mM NaCl
(Na+) internal	Always higher than (Na+) external		
(K+) internal	Always higher than (K+) external		
Cell size	Similar	Large increase	Slight decrease
Succulence	Slight increase	Large increase	Moderate increase
Ψ w internal	Higher than Ψ w external	Slightly higher than Ψ w external	Similar to Ψ w external
Ψ w internal	Approaches Ψ w internal	Decreases faster than Ψ w internal	Approaches Ψ w internal
Turgor	Decreases to 0	Increases	Decreases to 0

microshoots derived from treatments with 2.5% EMS were surviving in 100 mM NaCl (table 2). These microshoots are now being rooted and the resultant plants will be tested for NaCl tolerance. The mechanism of the increased NaCl tolerance is not clear, however, salt tolerant and the nonsalt tolerant microshoots could lead to the identification of genes involved in physiological responses to salt tolerance.

CONCLUSION

The responses of *A. canescens* var. *gigantea* plants, microshoots, and calli to various levels of external NaCl are summarized in table 3. A cellular basis for salt tolerance, as reflected in an ability of cultured cells to grow on high salt medium, is not evident for *A. canescens* var. *gigantea*. However, the ability to accumulate high levels of ions at all levels of tissue organization appears to be a characteristic with a strong cellular basis in this taxon. The study of *in vivo* and *in vitro* responses to NaCl provides potential for 1) gaining a greater understanding of salt tolerance, 2) the development of *in vitro* systems to increase salt tolerance, and 3) the isolation of genes involved in salt tolerance.

ACKNOWLEDGMENTS

I thank Dr. Ed King for the SEMs and Dr. Bjorn Martin for directing the water relations measurements. I particularly appreciate the introduction to *A. canescens* var. *gigantea* by Drs. C. M. McKell and H. C. Stutz. This work was supported in part by a grant from the U.S. Department of Energy, Short Rotation Woody Crops Program (MMESI 19X 89638C).

REFERENCES

Anderson, T. F. 1951. Techniques for the preservation of three-dimentional structure in preparing specimens for the electron microscope. Transactions of the New York Academy of Science Series II, 13: 130-134.

Ben-Hayyim, G.; Kochba, J. 1983. Aspects of the salt tolerance in NaCl-selected stable line of *Citrus sinensis*. Plany Physiology. 72: 685-890.

Croughan, T. P.; Stavarek, S. J.; Rains, D. C. 1978. Selection of a NaCl tolerant line of cultured alfalfa cells. Crop Science. 18: 959-963.

Daines, R. J.; Gould, A. R. 1985. The cellular basis of salt tolerance studied with tissue cultures of the halophyte grass *Distichlis spicata*. Journal of Plant Physiology. 119: 269-280.

Dix, P. J.; Street, H. E. 1975. Sodium chloride-resistant cultured cell lines from

Nicotiana *sylvestris* and *Capsicum* *annum*. Plant Science Letters. 5: 231-237.

Flowers, T. J.; Halls, J. L.; Warm, M. E. 1977. The mechanism of salt tolerance in halophytes. Annual Review of Plant Physiology. 29: 89-121.

Gale, J.; Naaman, R.; Poljakoff-Mayber, A. 1970. Growth of *Atriplex* *halimus* in sodium chloride salinated culture solutions as affected by the relative humidity of the air. Australian Journal of Biological Science. 23: 947-952.

Kelley, D. B.; Goodin, J. R.; Miller, D. R. 1982. Biology of *Atriplex*. In D. N. Sen and K. S. Rajpurohit, eds. Tasks for Vegetation Science, Vol. 2. D. W. Junk Publishers, The Hague. pp. 79-107.

Kelley, R. O.; Dekker, R. A. F.; Bluemind, J. G. 1973. Ligand-mediated osmium binding: its application in coating biological specimens for scanning electron microscopy. Journal of Ultrastructure Research. 45: 254-258.

Kleinkopf, G. L.; Wallace, A.; Cha, J. W. 1975. Sodium relation in desert plants. 4. Some physiological responses of *Atriplex* *confertifolia* to different levels of sodium chloride. Soil Science. 120: 45-48.

Lerner, H. R. 1985. Adaptation to salinity at the plant cell level. Plant and Soil 89: 3-14.

Longstreth, D. J.; Nobel, P. S. 1979. Salinity effects on leaf anatomy. Consequences for photosynthesis. Plant Physiology. 63: 700-703.

McKell, C. M. 1983. Genetic resources of unexploited native plants. Plant Molecular Biology Reporter. 1: 89-94.

Mozafar, A.; Goodin, J. R. 1970. Vesiculated hairs: a mechanism for salt tolerance in *A*. *halinus* L. Plant Physiology. 45: 62-65.

Murashige, T.; Skoog, F. 1962. A revised medium for rapid growth and bioassay with tobacco tissue cultures. Physiologica Plantarum. 15: 473-497.

Nabors, M. W.; Gibbs, S. E.; Bernstein, C. S.; Meis, M. E. 1980. NaCl tolerant tobacco plants from cultured cells. Zeitschrift Planzenphysiology. 97: 13-17.

Norton, J. A.; Caldwell, M. M.; Richardson, S. G. 1984. Sodium accumulation in *Atriplex*. U.S. Department of Energy. Washington, DC. 110 pp.

Osmond, C. B.; Bjorkman, D.; Anderson, D. J. 1980. Physiological process in plant ecology: towards a synthesis with *Atriplex*. Ecol. Studies No. 36. Springer, Berlin. 468 p.

Riehl, T. E.; Ungar, I. A. 1983. Growth, water potential, and ion accumulation in the inland halophyte *Atriplex* *triangularis* under saline field conditions. Acta Ecological Plantarum. 4: 27-39.

Scholander, P. F.; Bradstreet, H. T.; Hemmingsen, E. A. 1965. Sap pressure in vascular plants. Science. 148: 339-346.

Sharma, M. L. 1982. Aspects of salinity and water relations of Australian chenopods. In: D. N. Send and K. S. Rajpurchit (eds.). Tasks for Vegetation Science, Vol. 2. Dr. W. Junk, Pubs., The Hague. pp. 155-172.

Smith, M. K.; McComb, J. A. 1981. Effect of NaCl on the growth of whole plants and their corresponding callus cultures. Aust. J. Plant Physiology. 8: 267-275.

Storey, R.; Jones, R. G. W. 1979. Responses of *Atriplex* *spongiosa* and *Suaeda* *monoica* to salinity. Plant Physiology. 63: 156-162.

Strogonov, B. P. 1973. Salt tolerance in isolated tissues and cells. In: Structure and function of plant cells in saline habitats: new trends in the study of salt tolerance. B. Gollek, ed. Jerusalem, Israeli Program for Scientific Translation. pp. 1-33.

Stutz, H. C.; Melby, J. M.; Livingston, G. K. 1975. Evolutionary studies of *Atriplex*: a relic *gigas* diploid population of *Atriplex* *canescens*. American Journal of Botany. 62: 236-245.

Tal, M.; Heiken, H.; Dehan, K. 1978. Salt tolerance in the wild relatives of the cultivated tomato: responses of callus tissue of *Lycopersicon* *esculentum*, *L*. *peruviana* and *Solanum* *penellii* to high salinity. Zeitschrift fur Pflanzenphysiologie. 86: 231-240.

Tyree, M. T.; Hammel, H. T. 1972. The measurement of the turgor pressure and the water relations of plants by pressure-bomb technique. Journal of Experimental Botany. 23: 267-282.

Von Hedenstrom, H.; Breckle, S. W. 1974. Obligate halophytes? A test with tissue culture methods. Zeitschrift fur Pflanzenphysiologie. 74: 183-185.

Wallace, A.; Romney, E. M.; Mudean, R. T. 1982. Sodium relations in desert plants: 7. Effects of sodium chloride on *Atriplex* *polycarpa* and *Atriplex* *canescens*. Soil Science. 134: 65-68.

Welsh, S. L.; Stutz, H. C. 1984. Utah flora: Chenopodiaceae. Great Basin Naturalist. 44: 183-209.

Wetzstein, H.; Sommer, H. E. 1982. Leaf anatomy of tissue cultured liquid amber *Styraciflua* (Hamamelidaceae) during acclimatization. American Journal of Botany. 69: 1579-1586.

Wurtele, E. S.; Garton, S.; Young, D.; Balandrin, M. F.; McKell, C. M. 1987. Propagation of an elite high biomass genotype of *Atriplex* *canescens* by axillary enhancement. Biomass. 12: 281-291.

Section 2—Environmental Management and Technology

TRANSPLANTING OF NATIVE SHRUBS ON DISTURBED LAND IN THE MOJAVE DESERT

E. M. Romney, A. Wallace and R. B. Hunter

ABSTRACT: Restoration of native shrubs on disturbed land is a very slow natural process in the Mojave desert; however, the time required can be shortened markedly with managed transplanting and husbandry procedures. Tests conducted on denuded desert land in southern Nevada have shown that native shrubs can be transplanted at reasonable cost to obtain significant cover and density within a 5 to 7-year period by using selected species, by protecting them from grazing jackrabbits, and by supplying nutrient supplements.

INTRODUCTION

Findings presented are from experience gained from shrub transplanting work at the Nevada Test Site on land denuded by blading and grading. Study sites are located in shrub-dominated ecosystems in the Mojave desert and in the transition zone between the Mojave and Great Basin deserts. Shrub transplanting work is an ongoing program supported by the U.S. Department of Energy, Nevada Operations Office, to restore shrub vegetation onto land disturbed by energy development activities. From this program we have learned several things about what must be done to insure survival and growth of transplanted native shrubs within reasonable cost. Emphasis, therefore, will be placed upon procedural findings rather than upon data from specific experiments.

TRANSPLANTING METHODS AND MAINTENANCE

During earlier phases of this work, considerable effort was devoted to developing cost-effective methods for producing native shrub transplant specimens. This involved propagation from rooted cuttings and from seed germination (Wieland and others 1971). The goal was to learn how to restore a mixed population of native shrubs back to near-pristine state on denuded desert land. We found that this is possible; however, it is not economical due to the high cost of propagation and the slow growth and development of most native shrub species. In order to economically restore shrub vegetation onto large disturbed sites, it is more efficient to transplant only those species which are easy to propagate and which have hearty survival, growth and development characteristics. Mojave desert shrubs most suitable for transplanting are Atriplex canescens, A. polycarpa, A. lentiformis and Larrea tridentata. Ambrosia dumosa also does well in the Mojave Desert, but not in the transition zone between Mojave and Great Basin deserts. Great Basin desert species include Artemisia tridentata, Ceratoides lanata, Chrysothamnus nauseosus and Lycium andersonii. In cases where a broader mix of shrub is preferred for landscaping purposes, the costs for propagation and maintenance, plus time for growth and shaping, are principal limiting factors (Romney and others 1979, 1980, 1981).

Young Seedling Preparation and Planting

We found two procedural methods to be effective for large-scale shrub transplanting. One is to obtain 9 to 12-month old seedlings from commercial sources grown in 10-15 cm long tube-pack containers with arrangements for delivery to the job site for transplanting when it becomes frost-free in early spring. The best transplanting period for sites involved in this study is March through April, after which time supplemental irrigation is not usually required unless the preceding winter season precipitation was below normal. In most cases the top meter of soil on sites denuded for longer than a year will have adequate stored moisture to insure transplanted seedling survival, growth and development when spaced at densities of around 1000 plants per hectare. Commercial seedlings specimens normally are prepared with fertilizer supplement in sufficient amounts to carry the plants during the first season after transplanting. When it becomes necessary to transplant shrubs on sites with low soil moisture, we set out the seedlings with 2-3 liters of water and form a berm around each specimen to accommodate supplemental irrigation. Applications of 4-5 liters of water at 6-week intervals normally will satisfy needs through hot, dry summer months until fall season stress-dormancy occurs. The objective is not to promote succulent growth but rather to minimize the development of new foliage until succulent tissues harden over winter and the plants break dormancy with rapid growth and development the following spring. We rarely lose more than

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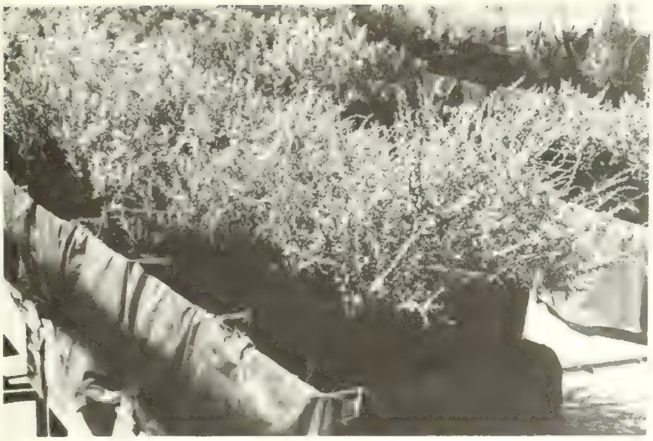

Figure 1--Shrub specimens potted in plastic tubes and grown under glasshouse conditions in preparation for transplanting.

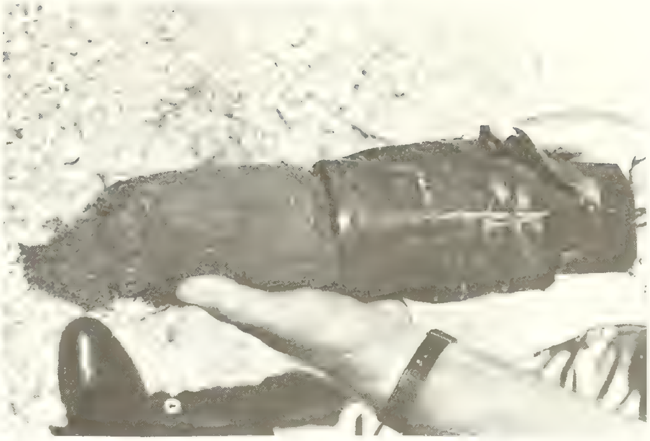

Figure 2--When transplanted, part of the potting tube is wrapped up around the root system to help reduce water loss to dry surface soil.

ten percent of transplanted specimens using the procedure described when adequate grazing protection from jackrabbits is provided.

Older Seedling Preparation and Planting

The second procedural method that has proved to be efficient is to propagate plant material on a continuing basis, and develop two or three-year old transplant specimens from excess commercial seedling stock, from seedlings germinated from locally collected seed, and from rooted cuttings. Seedling specimens are potted into 7.5 cm dia. flexible, black plastic tubes provided with slow bottom drainage. Tubes 35 cm long are filled to 30 cm with a one-to-one mixture of soil and vermiculite. A slow release, urea-based complete fertilizer pellet is placed near the bottom of each tube to provide a source of essential nutrients to the potted seedling. The potted shrub specimens are stored erect in plastic-lined holding boxes and developed under glasshouse conditions with minimum irrigation until transplanted (fig. 1). This procedure provides an ongoing stock of hardened shrub specimens to meet transplanting needs that are difficult to plan for and schedule. Such specimens can be transplanted any time between March and September irrespective of low surface soil moisture because of their deeper root configuration and greater moisture holding capacity. Upon transplanting, the lower half of the plastic tube is slipped up around the upper half when the shrub specimen is planted in a hole dug by hand or by power auger. Water (4-5 liters) is added to set the soil around the specimen and a berm is formed to accommodate later irrigation when required. The double ply of plastic around the upper half of the transplanted root system serves as an important barrier preventing moisture loss to the surrounding surface soil (fig. 2). Again, the first year objective is to avoid rapid growth of succulent foliage. For this reason supplemental water is applied only during the period between transplanting and onset of seasonal dormancy.

Grazing Protection for Transplanted Specimens

An important lesson learned is the necessity of providing each species of transplanted native shrub with adequate protection from grazing jackrabbits and livestock. One must decide, therefore, which kind of protective fencing is to be employed at given transplanting sites. Livestock grazing has been prevented since the early 1950's in areas of the Nevada Test Site of interest to our work, so we have only had to provide protection from jackrabbits. Depending upon the size of the job site and its future use, one may have an option of erecting a rabbit-proof perimeter fence around the transplanted area or of placing an individual fence around each shrub specimen. The cost for each method of fencing is about the same but each has certain advantages. Greater biomass can be obtained with perimeter fencing that prevents grazing, but the integrity of the fence must be maintained. In areas where perimeter fencing is not permitted, individual protective fences can be erected of size to prevent no grazing or to permit some grazing (compare fig. 3 and 4). Inasmuch as light grazing and pruning generally enhance growth and development of shrubs, we generally elect to protect each specimen with a dome-shaped cover made of 5 cm. dia. wire mesh netting that will keep jackrabbits from destroying the root crown but allow them to graze on shoots that protrude beyond the wire cover. The covers are made from 90 cm-wide poultry netting cut into 60 cm segments. The wire mesh is folded and the cut wire segments twisted together along each edge.

The open bottom of the formed cover is spread apart and placed over the transplanted shrub specimen. Soil pushed up around the cover to form an irrigation berm will lock the wire mesh in place (fig. 5). These covers do not need to be removed since shrub branches can grow out freely through the wire mesh openings. We have found that 90 cm-wide, 5 cm-dia. wire mesh attached to 120 cm-long steel fence posts at 3 meter spacing will provide rabbit-proof perimeter fencing. Wire

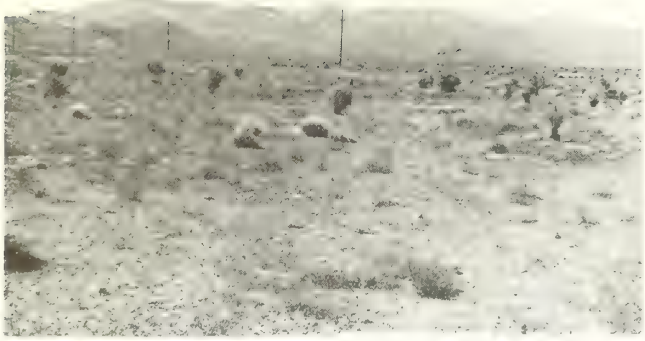

Figure 3--Seven-year-old transplanted shrubs protected with individual wire netting. Note loss of basal biomass to grazing jackrabbits.

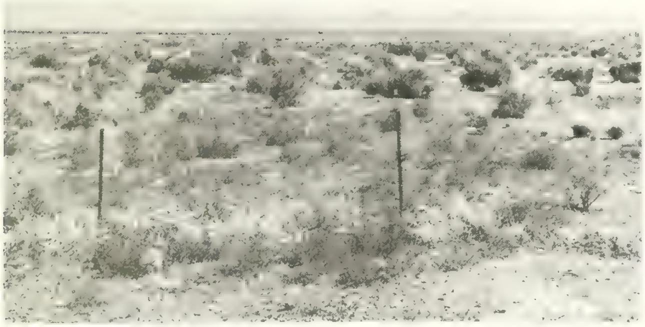

Figure 4-- Seven-year-old transplanted shrubs growing within rabbit-proof fenced enclosure. Note increased basal biomass when protected from grazing jackrabbits.

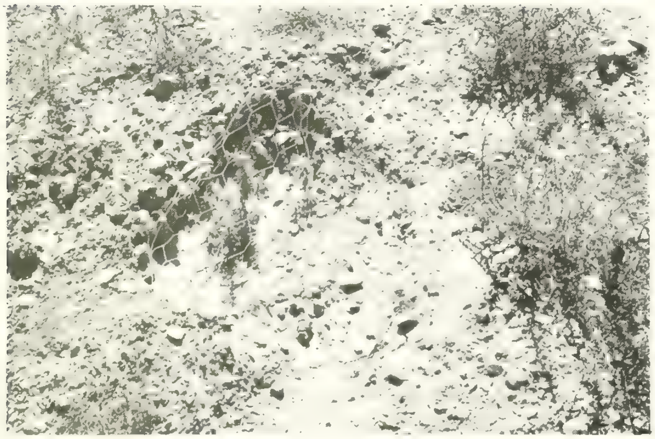

Figure 5--Transplanted shrub specimen with wire netting cover and shallow berm for adding water if needed.

need not be tacked to the ground between posts when erected on level land since the jackrabbit will not burrow underneath. Other burrowing small animals, except gophers, cause insignificant grazing damage. The problem with gophers will be discussed later.

RESULTS AND DISCUSSION

Several ecophysiological relationships influence the success of shrub transplanting on disturbed, denuded land and some will be addressed herein. If a broader treatise is desired, readers are referred to a series of papers in Great Basin Naturalist Memoirs, Number 4 (Wallace and others 1980).

Selection of Shrub Species

In order to economically restore shrubs onto disturbed Mojave desert land by managed transplanting methods, one must be satisfied to use only a few species that are easy to propagate and that survive and grow well under the harsh environmental conditions. We have listed above those species which are the most easy to propagate, hearty to survive and which undergo rapid growth and development after transplanting. Sufficient time has not passed at any of our study sites to experience natural input of slower growing species, but our planting density of around 1000 plants per hectare provides plenty of room between plants for other shrub species to become established. New progeny seedlings have appeared around transplanted host shrubs within five years, but they generally do not survive unless they are protected from grazing animals. By using those shrub species listed with the transplanting and fencing methods described above, the cost for producing transplant specimens and placing them onto disturbed sites with protection from grazing jackrabbits ranges from 3 to 5 dollars per specimen.

An additional problem worth mentioning is competition that occurs for soil moisture from the summer annual Salsola species that commonly invade disturbed land areas at the Nevada Test Site (fig. 6). Those annual plants are fierce competitors because of their unique germination, survival, and growth characteristics (Rhoades and others 1967; Wallace and others 1968). They should be removed from around the transplanted shrubs to reduce competition for available water.

Animal Grazing Problem

It was mentioned above that all livestock grazing has been curtailed at our study sites, but it should be a problem at sites requiring shrub revegetation elsewhere on open rangeland. It is imperative that transplanted shrubs be adequately protected from grazing jackrabbits (Lepus californicus) and gophers (Thomomys bottae) in order to insure survival. While the effect from gophers might not be immediate, as is the case with jackrabbits, the long-term effect is disastrous. For example, 162 transplanted specimens consisting of 14 different shrub species planted in 1972 were

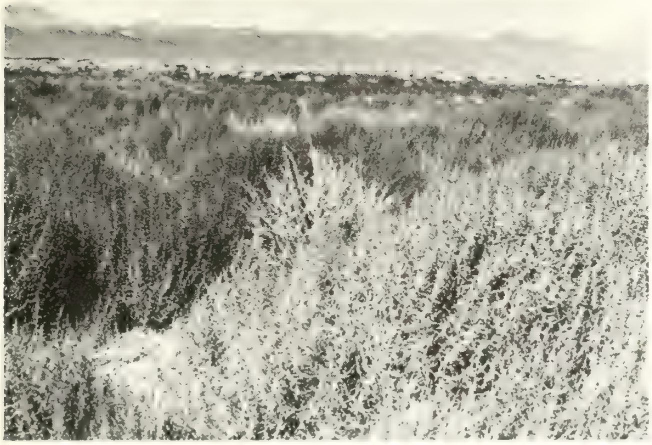

Figure 6--Illustration of competition problem between the transplanted shrub located at center of photo and surrounding summer annual Salsola population.

reduced to 110 in 1973, 60 in 1977, 50 in 1978, 22 in 1983 and 7 in 1986 in an area infested by pocket gophers. It is not economical to transplant shrubs into gopher infested areas unless chemical eradication measures have been taken. Even then there may be long-term losses as revegetated sites become reinfested.

In several instances we have lost virtually overnight almost all transplanted shrubs set out without fencing to protect them from grazing jackrabbits. One must realize that an average 5-6 kg animal requires up to 200 gm of succulent plant foliage daily in order to obtain sufficient water for survival. Their target material grazed for food and water is principally new shrub seedlings; therefore, aside from drought, jackrabbits are simply the single most limiting factor governing natural restoration of shrubs in the Mojave desert. We have demonstrated at bladed and graded sites that shrub recovery can be enhanced markedly by protecting new seedlings, new crown sprouts, and resprouts from sheared-off root systems with wire mesh covers at the start of the spring growing season after disturbance has occurred (Hunter and others 1985). Problems resulting from transplanting shrubs later during the summer season become intensified because jackrabbits will seek out the succulent plant material for water and consume all unprotected, aboveground tissue.

Nutritional Supplements

Blading and grading Mojave desert land not only destroys long-standing vegetation, but it also destroys the delicate fertile islands formed underneath shrubs over long periods of time (Romney and others 1980). A major problem in shrub restoration is to restore that nutrient resource to the disturbed area. We have tried several methods to do this, including the addition of chemical fertilizers by dry broadcast and also wet applications onto the surface, by addition of nutrients to irrigation water, and by the addition of steer manure and sewage sludge amendment both onto the surface and mixed into pocket zones. Surprisingly, the best and most cost-effective method proved to be the one described of placing slow-release, complete fertilizer pellets in the potting tube while preparing shrub seedling specimens for later transplanting. This does not imply that the other methods are ineffective; they can be effective when the fertilizer supplements are applied sparingly. The situation is that, since native shrubs are relatively slow growing, they do not require very high levels of soil fertility. In fact, the addition of fertilizer in amounts and by methods normally applied to agricultural crop plants will often inhibit shrub growth unless accompanied by supplemental irrigation or rainfall. We believe that this results from the addition of more salt to soils already high in soluble minerals.

REFERENCES

Hunter, Richard B.; Romney, E. M.; Wallace, A. 1985. Revegetation on disturbed desert land at NUWAX and SEDAN. USDOE Report NV-272.

Rhoads, William A.; Frolich, E. F.; Wallace, A. 1967. Russian thistle seeds. Calif. Agr. 21(7):2.

Romney, Evan M.; Hunter, R. B.; Wallace, A. 1979. Revegetation studies pertinent to the Barstow 10 MWe Pilot Solar Thermal Power System and to potential power plant sites elsewhere in the Mojave desert. UCLA Report 12-1224.

Romney, Evan M.; Hunter, R. B.; Wallace, A. 1980. Vegetation management and recovery at sites disturbed for solar thermal power systems. UCLA Report 12-1281.

Romney, Evan M.; Wallace, A.; Kaaz, H.; Hale, V. Q. 1980. The role of shrubs on redistribution of mineral nutrients in soil in the Mojave desert. Great Basin Naturalist Memoirs 4:124-133.

Romney, Evan M.; Hunter, R. B.; Wallace, A. 1981. Experiments on restoration of disturbed desert lands by means of revegetation. UCLA Report 12-1312.

Wallace, Arthur; Rhoads, W. A.; Frolich, E. F. 1968. Germination behavior of Salsola as influenced by temperature, moisture, depth of planting, and gamma radiation. Agronomy Journal 60:76-78.

Wallace, Arthur and others. 1980. Soil-plant-animal relationships bearing on revegetation and land reclamation in Nevada deserts. Great Basin Naturalist Memoirs, Number 4.

Wieland, Paul A. T.; Frolich, E. F.; Wallace, A. 1971. Vegetative propagation of woody shrub species from the northern Mojave and southern Great Basin deserts. Madrono 21:149-152.

PULSE ESTABLISHMENT OF WOODY SHRUBS ON DENUDED MOJAVE DESERT LAND

E. M. Romney, A. Wallace and R. B. Hunter

ABSTRACT: Denuded Mojave desert land usually requires decades of time for restoration of woody shrubs through natural revegetation processes. We had opportunity to observe pulse establishment of *Ambrosia dumosa* and *Larrea tridentata* onto land that had been disturbed by grading followed by rare events of above-normal rainfall in southern Nevada. Grazing jackrabbits severely damaged unprotected new shrubs. Findings on survival and development of cohort seedling populations indicate that this pulse-triggered establishment of new shrubs resulted from two successive years of above-normal summer rainfall, plus normal winter precipitation, following the year of germination.

INTRODUCTION

Woody shrubs in Mojave desert ecosystems are long-lived, and their turnover in established populations is correspondingly slow (Shreve and Hinckeley 1937; Johnson and others 1975; Beatley 1976, 1980; Hunter and others 1980; Vasek 1980). There are, however, distinct age classes in shrub populations, indicating that periodic pulse establishment normally occurs (El-Ghonemy and others 1980; Romney and others 1980). Storm-initiated germnination followed by high seedling mortality is typical of those ecosystems (Went and Westergaard 1953; Sheps 1973; Ackerman 1979).

Mojave desert land denuded by various kinds of disturbance usually requires decades of time before woody shrubs regain even a semblance of original cover and density (Vasek and others 1975; Romney and others 1980; Wallace and others 1980; Webb and Wilshire 1980). Land at the Nevada Test Site in southern Nevada has been denuded at various locations by different kinds of energy development activities. We present herein some observations and data on pulse-triggered establishment of woody shrub seedlings on northern Mojave desert land denuded by grading.

EXPERIMENTAL SETTING AND METHODS

An area in Jackass Flats was denuded by grading to a depth of 15-20 cm in April, 1979, after which it was occupied as a military bivouac area for six weeks until abandoned. The area was then made available for conducting revegetation experiments within a Mojave desert shrub community dominated by *Larrea tridentata* and *Ambrosia dumosa*. The alluvial soil of the area is sandy to depths greater than one meter. Our interest at this particular site was an opportunity to investigate regrowth of woody shrubs from new sprouts on sheared-off root systems.

Periodically we have encountered examples of shrub rejuvenation from new sprouts on exposed and sheared-off root systems. This has been observed mainly with *Larrea tridentata*, *Lycium andersonii*, and *Ephedra nevadensis*, but it probably occurs with other shrub species as well. The question arose concerning the extent to which one might speed up natural revegetation by protecting new sprouts on sheared-off root systems from grazing animals.

The recently graded site provided an opportunity to investigate this process and develop cost-effective procedures to compare with transplanting methods that have proved to be successful. We learned from earlier shrub transplanting experience that the transplanted specimens need protection from grazing rabbits in order to assure their survival. That problem arose not from normal pruning of shoots, which is beneficial in promoting new growth, but from excessive pruning of palatable shoots down to (and often including) the root crown. Jackrabbits have shown preference for grazing on transplanted shrub specimens even when succulent native vegetation is standing nearby; we presume that a sense of taste is involved.

After summer rainfall in May and July, 1979, new sprouts grew on exposed roots and denuded crowns of *Ambrosia dumosa* and *Larrea tridentata*. Specimens located within a one-hectare area were measured for size and covered with wire mesh screens for protection against overgrazing by jackrabbits. Survival and growth of this population was monitored periodically until December 1983.

Concurrently with the root and crown sprout experiment, we transplanted some specimens of *Atriplex canescens* and *Larrea tridentata* onto the graded site with and without protective screen covers. Virtually all of the unprotected transplants had been destroyed by December, 1980, and none survived until October 1981. Jackrabbits

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Authors are Research Scientists, Laboratory of Biomedical and Environmental Sciences, University of California, Los Angeles, CA. Support was provided by the Health Physics and Environmental Division, USDOE Nevada Operations Office.

also had grazed on foliage of Larrea that extended beyond the screen covers, and the animals had kept the foliage of Atriplex clipped back to the screen wire which we observed each time we visited the study site through December 1983. Again, we presume that a sense of taste might be involed since we produce the transplant specimens in glasshouse under high nutritional conditions.

Two cohort populations of randomly spaced Ambrosia dumosa seedlings that germinated in the graded area following summer rainfall in 1981 were marked in April 1982 to follow survival and development. Another cohort population of A. dumosa seedlings was identified in one square meter quadrats along 50-meter belt transects in both the graded and adjacent undisturbed areas after pulse-triggered germination of new seedlings following above-normal rainfall in August 1983. What followed was an unusual pulse of survival and development of new shrubs in the graded area concurrent with subsequent years of above-normal summer rainfall, plus normal winter precipitation.

RESULTS AND DISCUSSION

Table 1 contains data on survival and growth of shrubs from resprouts on sheared-off root systems that had been covered with protective screens. Specimens marked and left unprotected did not survive overgrazing by jackrabbits and stress from late summer and fall drought in 1980. We observed that some jackrabbit grazing on new sprouts had occurred at the time the study population was marked, and we continued to find evidence that jackrabbits grazed from foliage that had grown outside of the protective screen covers when we made periodic visits to the graded study site through the remainder of 1979, 1980, and 1981. Very heavy grazing occurred during the late fall drought period of 1980, especially on Ambrosia dumosa, but the screen covers prevented destruction of the new sprouting crowns. Loss of some new sprout specimens occurred for other reasons than overgrazing, presumably from severe moisture stress. However, during the five-year observation period, at least one half of the original new sproutings had become well established shrubs of vigorous size (table 1 and figures 1 and 2). Our findings suggest that the practice of placing screen wire covers over succulent resprouts on sheared-off shrub root systems to protect them from overgrazing by jackrabbits is an inexpensive way to help speed up the restoration of shrubs onto disturbed and denuded Mojave desert land.

Table 1--Survival and growth of Ambrosia dumosa and Larrea tridentata shrubs from resprouts on sheared-off root systems protected by wire screens

Observation Time	Surviving population	Mean size cm^3 ± S.E.
		(x 10^3)
Ambrosia dumosa		
August 1979[1]	34	0.25 ± 0.7
August 1980[1]	29	22.4 ± 2.8
December 1980[2]	24	4.4 ± 1.0
October 1981[1]	23	26.7 ± 3.8
December 1983	18	241 ± 30
Larrea tridentata		
August 1979[1]	27	2.7 ± 0.8
August 1980[1]	17	15.0 ± 4.0
December 1980[2]	16	32.0 ± 6.0
October 1981[1]	15	131 ± 26
December 1983	15	836 ± 162

[1] **Lightly grazed by jackrabbits.** [2] **Heavily grazed.**

The first opportunity to observe pulse-triggered establishment of shrub seedlings on the graded area in Jackass Flats resulted from thunderstorm systems that impacted that site during summer months of 1981. Table 2 gives precipitation data measured at a location 11 km from the graded site

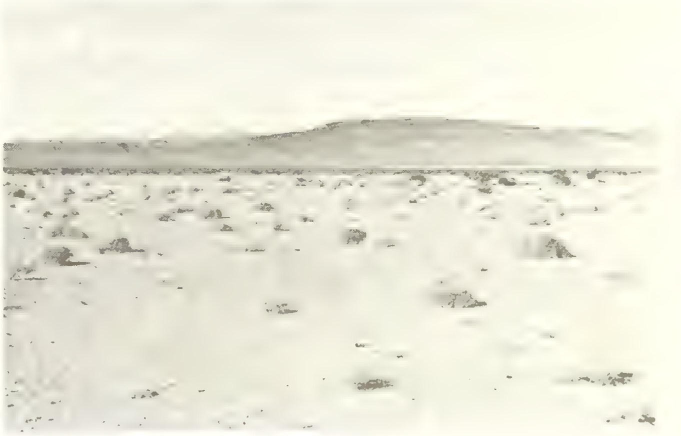

Figure 1--View of the graded area in Jackass Flat taken August 1982. The larger shrubs are resprouts from sheared-off root systems protected from overgrazing by jackrabbits after August 1979.

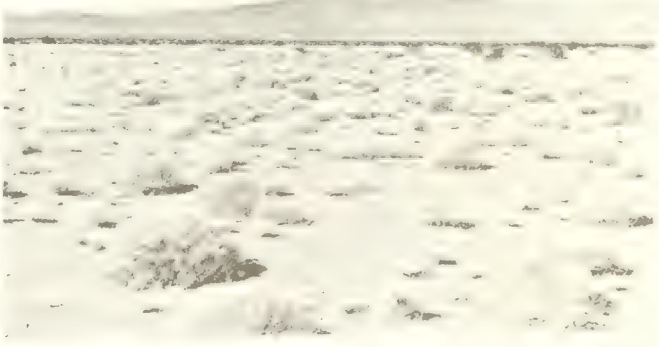

Figure 2--View of the graded area taken in October 1985 after pulse establishment of new shrubs following successive years of above-normal summer and normal winter precipitation in 1983 and 1984.

Table 2--Precipitation (mm) at U.S. Weather Bureau Station located 11 km NE of graded study site at comparable elevation

Month	1978	1979	1980	1981	1982	1983	1984	1985
January	58.2	27.9	38.3	06.6	05.3	31.2	00.0	12.7
February	73.9	13.2	25.6	00.2	06.1	09.1	03.8	03.1
March	76.2	34.8	44.9	41.6	42.6	76.2	00.0	02.8
April	13.4	00.2	02.5	00.2	07.1	08.1	00.3	00.0
May	00.1	10.4	10.4	18.0	07.8	12.2	00.0	25.6
June	00.0	00.0	01.7	00.0	00.0	00.0	00.0	00.8
July	02.5	13.9	05.1	20.3	01.5	00.0	114.3	09.4
August	01.0	08.9	00.0	05.1	11.4	98.8	44.2	00.0
September	22.8	00.0	05.8	08.4	10.1	06.8	07.6	17.1
October	17.5	00.0	00.0	00.0	00.5	02.0	03.8	01.5
November	19.0	00.2	00.0	08.9	16.7	13.9	25.2	27.4
December	10.1	08.9	00.0	00.0	06.3	21.6	61.7	04.3
Total	294.7	118.4	134.3	109.3	115.4	279.9	260.6	104.7

Table 3--Survival and growth of *Ambrosia dumosa* seedlings on graded site in west Jackass Flats

Time and Group	Survival	Mean Size	[1]Growth Constant
	n	cm^3 ± S.E. ($x10^3$)	k
April 1982			
Group 1	31	6.9 ± 1.1	
Group 2	31	7.9 ± 1.3	
November 1982			
Group 1	30	30 ± 7	2.9*
Group 2	29	22 ± 4	2.0
December 1983			
Group 1	27	189 ± 25	1.9
Group 2	29	153 ± 20	2.1

[1] Growth constant, k = [size 1/size 2] t; in years.
*significantly different at p = .05 by signed rank test.

at comparable elevation. Table 3 gives data on survival and growth of two cohort groups of *Ambrosia dumosa* seedlings that was attributable to successive years of above-normal summer and winter precipitation following germination.

A large pulse of new shrub seedling germination also was triggered again during the years of 1983 and 1984, but the establishment pattern was extremely different between the graded area and the surrounding natural vegetation area (table 4). Within three years after pulse germination, cover and density of new *A. dumosa* shrubs in the graded area exceeded that of adult shrubs in the surrounding undisturbed area (Hunter 1987). Figures 1 and 2 are views illustrating new shrub seedling establishment on the graded area over a 3-year period. Pulse-triggered germination of new shrub seedlings in the undisturbed area was as high as 170 per m^2, but proportionally few survived from environmental stress factors, including grazing jackrabbits. As many as 20 seedlings per

Table 4--Survival of pulse germination of *Ambrosia dumosa* seedlings in m^2 quadrats along 50-meter belt transects across a graded and undisturbed site in west Jackass Flats. Seedlings were counted on January 11 and August 17, 1984, and on September 11, 1987

[1]Quadrat	Bladed Site			[1]Quadrat	Undisturbed Site		
	Jan. 84	Aug. 84	Sep. 87		Jan. 84	Aug. 84	Sep. 87
1	48	22	20	1	151	5	1
2	23	11	8	2	204	3	0
3	25	4	5	3	318	26	6
4	17	5	6	4	438	11	3
5	43	16	11	5	124	9	1
6	71	21	13	6	418	23	6
7	28	5	6	7	864	4	0
8	40	13	13	8	115	3	0
9	14	9	8	9	805	9	0
10	97	20	19	10	195	28	3
Total	406	126	109	Total	3,632	121	20

[1] Grouped in sets of 5 m^2 for convenience of listing in table.

m^2 were counted on the graded area of which a greater proportion survived and made a marked impact as viewed in figure 2. Because of the combination of stresses from competition with adult shrubs for water and from animal grazing, relatively few new seedlings survived in the surrounding undisturbed area as compared to the higher number of seedlings that survived on the graded site. We also found that the proportion of seedlings of different shrubs and grass was unexpected. For example, on one transect of 1 m x 150 m there were 5,527 *A. dumosa* seedlings, 15 *Larrea tridentata* seedlings, 3 *Acamptopappus shockleyi* seedlings and 43 *Oryzopsis hymenoides* seedlings (Hunter 1987).

Competition for water among new shrub seedlings was completely different in the graded and the adjacent, undisturbed area. The cohort of new shrub seedlings in the undisturbed area was surrounded by old adult shrubs in competition for available water. Therefore, relatively few seedlings survived beyond the first year after germination and grew to 5-cm size in any dimension within the observation period. In the graded area there was no competition for water between new seedlings and adult shrubs, except around the border where the suppressed size of established seedlings was evident within 5 to 7 meters from undisturbed, adult shrubs. Farther out into the graded area the surviving seedlings did not compete with one another, so they continued vigorous growth and development. Inasmuch as water did not become limiting in the graded area, the result was a phenomenal display of new shrub growth and development during the successive years of above-normal precipitation in 1983 and 1984. Competition between young plants for longer term survival is an interest that we shall continue to follow with this new shrub population.

REFERENCES

Ackerman, Thomas L. 1979. Germination and survival of perennial plant species in the Mojave desert. Southwest Naturalist 24:399-408.

Beatley, Janice C. 1976. Vascular plants of the Nevada Test Site and central-southern Nevada. Report TID-26881, 308 pages, National Technical Information Center, Springfield, VA.

Beatley, Janice C. 1980. Fluctuations and stability in climix shrub and woodland vegetation of the Mojave, Great Basin and transition deserts of southern Nevada. Israel Journal of Botany 28:149-168.

El-Ghonemy, Ali A., Wallace, A., Romney, E. M. 1980. Multivariate analysis of the vegetation in a two-desert interface. Great Basin Naturalist Memoirs 4:42-58.

Hunter, Richard B., Romney, E. M., Wallace, A., Kinnear, J. E. 1980. Residual effect of supplemental moisture on the plant populations of plots in the northern Mojave desert. Great Basin Naturalist Memoirs 4:24-27.

Hunter, Richard B. 1987. Competition between adult and seedling *Ambrosia dumosa* in the Mojave desert. (Submitted).

Johnson, Hyram B., Vasek, F. C., Yonkers, T. 1975. Productivity, diversity and stability relationships in Mojave desert roadside vegetation. Bulletin of the Torrey Botany Club 102:106-115.

Romney, Evan M., Wallace, A., Hunter, R. B. 1980. The pulse hypothesis in the establishment of *Artemisia* seedlings at Pahute Mesa, Nevada. Great Basin Naturalist Memoirs 4:28-30.

Sheps, Leon O. 1983. Survival of *Larrea tridentata* S. & M. seedlings in Death Valley National Monument, California. Israel Journal of Botany 22:8-17.

Shreve, Forrest, Hinckeley, A. L. 1937. Thirty years of change in desert vegetation. Ecology 18:463-478.

Vasek, Frank C., Johnson, H. B., Brum, G. D. 1975. Effects of power transmission lines on vegetation of the Mojave desert. Madrono 23:114-130.

Vasek, Frank C. 1980. Creosote bush: long-lived clones in the Mojave desert. American Journal of Botany 67:246-255.

Wallace, Arthur, Romney, E. M., Hunter, R. B. 1980. The challenge of a desert: revegetation of disturbed desert lands. Great Basin Naturalist Memoirs 4:216-225.

Webb, Richard H., Wilshire, H. G. 1980. Recovery of soils and vegetation in a Mojave desert ghost town. Journal of Arid Environments 3:291-303.

Went, Fritz W., Westergaard, M. 1953. Ecology of desert plants. III. Development of plants in the Death Valley National Monument, California. Ecology 30:26-38.

HIGH-TECH POLYACRYLAMIDES AS SOIL CONDITIONERS IN THE RECLAMATION AND STABILITY OF DESERT LANDS

Garn A. Wallace and Arthur Wallace

ABSTRACT: Water-soluble polyacrylamide polymers with appropriate characteristics serve several useful purposes in land reclamation projects. They are especially economically affordable when applied in irrigation water, although they may also be applied to soil as dry granules. When applied to tilled soil, soil aggregates are made more water stable with resulting increases in pore space in soil. Less surface crusting, improved water penetration and drainage, more resistance to erosion, less capillary rise of salty water are among the effects which follow. Although these soil conditioners replace the need for addition of large quantities of organic materials to the soil in the reclamation process of desert lands, best effects are achieved when the polymers and a modest amount of organics are applied together. When soils are saline and sodic, the use of the polymers results in making soil more permeable so that salts are more easily leached, and applied gypsum is more effective in replacing sodium on the clay in the soil. Waste management involving arid lands can be improved in combination with use of the new polymers.

INTRODUCTION

Although super absorbent water-insoluble polymers have uses in soil preparation (Azzam 1985; Henderson and Hensley 1986), they are not the subject of this paper. The polymers that swell on addition of water to sometimes several hundred times their volume are cross-linked to achieve that property. These cross-linked polymers can be useful, especially in sandy soils low in water-holding capacity. They are available to the home and landscape trades.

In 1952 Soil Science (Bear 1952) published a set of papers that introduced synthetic polymer soil conditioners to the scientific community. Monsanto Chemical Company released a product known commercially as Krilium. Enthusiasm was high during the early 1950s because of the urgent need for improving the physical properties of soils; however, the realization that the methodology was too expensive for use became apparent after a few years. It was also too expensive for specialty uses, although other problems resulted in its total withdrawal from the market in the early 1960s.

Worldwide interest has continued in this area until the present time. Several reviews and symposia have monitored progress in the field. Azzam (1980) reviewed the subject including over 500 references. In our own work we had used the Monsanto product of Krilium all during the 1960s and 1970s, having obtained a large supply when it was still available. Azzam's review caused us to examine a number of new polymer chemicals as soil conditioners, some of which were already in our laboratory for other reasons, and we also prepared some in our laboratory.

Emerging from the pieces of work is the hope of a new technology that can easily and economically remove the most important remaining barrier or limiting factor to soil improvement. This barrier is poor physical properties of soil, which limits water movement, root development, and aeration of the soil.

As the world gears up for new major advancements to result from biotechnology and genetic engineerings, soil scientists must concern themselves with the creation of soil conditions that would permit full expression or full potential of the new developments. New high technology soil conditioners can help make this possible.

With new soil conditioner materials and new methods of application, the amount of soil conditioner needed to improve a given area of land can approach two orders of magnitude less than that used 35 years ago (Wallace and Nelson 1986).

The new water-soluble soil conditioners may, if used according to established procedures

1. Increase pore space in soils containing clay.
2. Increase water infiltration into soils containing clay.
3. Prevent soil crusting.
4. Stop erosion and water runoff.
5. Make friable soil that is easy to cultivate.
6. Make soil dry quicker after rain or irrigation so that the soil can be worked sooner.

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Garn A. Wallace is Plant Biochemist, Complete Green Company, 2066 Westwood Boulevard, Los Angeles, California 90025.

Arthur Wallace is Research Plant Physiologist, Laboratory of Biomedical and Environmental Sciences, University of California at Los Angeles, 900 Veteran Avenue, Los Angeles, CA 90024-1786, operated for the U.S. Department of Energy by the University of California under contract No. DE-AC03-76-SF00012.

Consequently, these translate into

1. Stronger and larger plants with more extensive root systems.
2. Earlier seed emergence and crop maturity.
3. More efficient water utilization.
4. Easier weed removal.
5. More response to fertilizers and amendments.
6. Less plant disease related to poor soil aeration.
7. Decreased energy requirements for tillage.

These developments will also make it possible to better achieve land reclamation, especially in difficult situations (Ferguson and Frischknecht 1983).

CONTROL OF SOIL EROSION BY POLYMERIC SOIL CONDITIONERS

Soil losses resulting from action of rain have been a tremendous problem to man since his beginning (Black and Adams 1984; Crosson and Stout 1984; Wallace and Wallace 1986). The impact of a raindrop on unprotected soil tends to break down soil structure, and surface flow transports the detached soil. Air escaping from aggregates immersed in water causes them to explode if they are unstable (Kemper and others 1985). The slaking that results can lead to either sheet or gully erosion. If water reaches the same aggregates very slowly, however, they may not explode. A well-known control of erosion by water is the establishment of a vegetative cover where possible. Grasses are commonly established to serve this purpose as they cushion the fall of raindrops and minimize the slaking or detachment of soil particles. With surface soil stabilized in this manner, infiltration is increased, and runoff and erosion are reduced.

Because grass is usually established by seeding, erosion must be temporarily controlled until the grass is adequately developed. Vegetative mulches, usually consisting of straw, hay, or grass, are generally applied over newly seeded sloping surfaces. Disadvantages of mulches include flammability, bulk, unsightliness, high-application costs, and, in many instances, unavailability of mulch (Weeks and Colter 1952).

The resistance of soils to erosion is related to the components of soil organic matter that produce stable structure in soil. A friable crumb structure that is resistant to slaking by water is less likely to result in soil movement during rain or irrigation. The essence of arable soil is the presence of sufficient stable organic compounds capable of binding clay particles into water-stable aggregates. Not all organic materials are capable of forming water-stable aggregates, however. Decaying organic matter releases some substances that are capable of aggregating soil (Oades 1984). Bacterial slimes and fungal mycelia are important means of soil aggregation.

In an experiment, simulated rainfall (12.7 mm in 2 min) was applied to 11.4 by 11.4-cm containers. The polyacrylamide was applied simulating an aerial application (crop dusting airplane) for the dry applications. The soil was on a 15° slope. The results indicate that the rate 16.8 kg ha^{-1} of the polyacrylamide applied to the soil surface as a dry powder fully stopped erosion under the conditions tested (table 1). The lower rates were also highly successful. The polymer applied in solution was fully effective in stopping erosion.

Table 1--Effect of dry-broadcasting a polyacrylamide on damp soil for erosion control

Treatment	Rate of polyacrylamide kg ha^{-1}	Erosion MG ha^{-1}	Reduction %
	Sandy clay (crusting soil) from Lancaster, Calif.		
Control	0.0	5.10	-
Level 1	5.6	0.57	89.7
Level 2	11.2	0.14	97.3
Level 3	16.8	0.00	100.0
0.15% Polymer in solution	73.0	0.00	100.0
	Yolo loam from West Los Angeles, Calif.		
Control	0.0	4.45	
Level 1	5.6	1.11	75.0
Level 2	11.2	0.33	92.6
Level 3	16.8	0.08	98.2
0.1% Polymer in solution	33.6	0.00	100.0

Several uses of the polyacrylamide polymers for soil erosion control are possible, and practical research must be continued for a number of years on each of these.

On hillsides where rain or irrigation cause surface runoff with gullying or other types of soil movement, polymers can be mixed into the soil at various depths. This will increase infiltration into soil and give more time for rainwater or irrigation water to percolate to different depths and thus decrease the chance for soil erosion. In some cases the polymer can increase the water-holding capacity of the soil. This method of erosion control can lead to soil becoming saturated, which happens when infiltration is high to given depths. If the incline is great enough, the weight of the saturated soil could cause slippage, although this is less likely when there is no imported soil. The greater the depth of treatment, the greater the amount of water that can be stored in the soil and retained for deep percolation.

In another procedure, conditions are the same as for above except that the polymer is supplied only to the surface 1 to 3-cm depth. This is best done with sprinkler irrigation; 0.5 to 1.5 cm of water would be needed. This will also increase infiltration, but perhaps at a slower rate than above. Under intense rain there then would be the possibility of some runoff, but the stable aggregated soil surface would have a decreased tendency to move. This controlled runoff would decrease the chances of having supersaturated soil that could slip under some conditions, especially when fill soil is involved. Effects can be controlled by the concentration of polymers in the irrigation water; a useful range could be 1 to 500 mg L^{-1}.

Another procedure involves spraying polymers in solution or applying dry polymers followed by wetting onto the soil surface. After drying, the stable structure of the surface of soil will not easily break during rain, even though water will penetrate, but with much running off. The soil should not be cultivated in this situation. Another procedure involves applying polymers to soil via irrigation water to decrease soil erosion by the irrigation water, particularly from furrows. Still an other procedure involves applying polymers to open fields to decrease erosion of dust by wind (Chepil 1954).

AMELIORATION OF SODIC SOILS WITH POLYMERS

Sodic soils generally have poor physical properties (Gupta and others 1984; Helley 1937; Richards 1954), and this leads to poor plant growth and makes land reclamation difficult. A high sodium adsorption ratio, a high soil pH, and simultaneously high levels of CaCO$_3$ contribute to the dispersion behavior of soils that give poor aeration, poor water intake, poor drainability, and that resist cultivation. Under unfavorable conditions, even humic substances can enhance dispersion of soil (Gupta and others 1984). Swelling contraction of certain clays under sodic conditions and low salt water also contributes to poor physical properties of soil (Aldrich and Schoonover 1951; Gupta and others 1984; Helley 1937).

Any means of increasing the soluble Ca in the soil does improve the characteristics of sodic soils (Aldrich and Schoonover 1951; Richards 1954). Gypsum, soluble CaCO$_3$, and acidifiers of calcareous soils can improve sodic soils. Associated leaching is essential; but at least initially, this is difficult to achieve.

Quastel (1954) pointed out that the soil conditioner CRD-186 (Allison and Moore 1956), when applied to alkaline and saline soils, facilitated the removal of salt and exchangeable Na with irrigation. In the Soviet Union, Khamraev and others (1983) found that the structure of alkaline-sodic soils was improved and that salts were more easily washed from soils when treated with a polyelectrolyte. The efficacy of the treatment increased with increasing molecular weight of polymer, and it decreased with increasing hydrolysis of the polymer. Allison (1952) and Allison and Moore (1956) showed that synthetic soil conditioners can provide stability to sodic soils.

Gardner commented that a soil conditioner must be less expensive than gypsum to be competitive (see Barrada 1972), but failed to state that quantities must also be considered. For example, 2 to 10 kg polymer soil conditioner must be compared with from 2 to 20 MG gypsum; even so, their effects are mostly different. In the studies of Allison (1952), the polymer treatments gave manifold increases in the rate of water infiltration. Sweet corn yields were about doubled in saline-alkaline soils by the conditioners, but they had less effect on non-alkaline-saline soil. Exchangeable sodium was also decreased by the treatments.

The results of all the 35-year-old studies are valid (Wallace and others 1986). Today, however, new polymer soil conditioners and application procedures are available that can decrease by 100 or more times the rates needed to achieve the same results.

Table 2--Retention, %, of soil particles on sieves of different size openings with application of soil conditioners to a sodic soil from Lost Hills, California[1]

Sieve openings	Control	56 kg Polyacrylamide ha-^{1}
mm	% of 50 g retained, cumulative	
0.589	2.0	2.7
0.295	7.3	66.2
0.149	22.2	81.6
0.104	27.4	83.5
0.059	38.6	84.7
Bottom	100.0	100.0
	% in bottom container	
	61.4	15.3
	Δ% for 0.104 sieve opening or greater	
		56.1

[1] Sieves, other than control, were drenched with solution containing 0.5 mg L^{-1} appropriate polymer.

Table 3--Time needed for infiltration of water through stabilized and unstabilized sodic soil from Lost Hills, California

Treatment rates anionic polyacrylamide kg ha^{-1}	Infiltration time for 25 ml in 25 g soil, s	Strength of aggregates in water
0	270	Feeble
28	95	Marginal
56	70	Very good
112	45	Strong
168	45	Strong
224	45	Strong

We applied new-generation soil conditioners to sodic soils in various procedures. In flocculation tests, followed by wet-sieving, particle sizes were approximately four to five times larger with new soil conditioners than with controls (table 2). Water penetration was greatly improved on a sodic soil when conditioned with a new soil conditioner (table 3).

ENHANCEMENT OF THE EFFECT OF COAL FLY ASH BY A POLYACRYLAMIDE SOIL CONDITIONER

In producing energy by burning coal, the United States produces about 40 million MG of fly ash per year (Babu 1975; Bond and others 1972). Even though there are agricultural and reclamation uses for it as a soil amendment (Faber 1976; Hodgson and others 1972; Jastrow and others 1981; Martens and Beahm 1978; Phung and others 1978; Terman and others 1978), the supply is greater than present use. As a consequence, large quantities of it are piling up. There is some environmental hazard due to the erodibility of the stockpiles. The objective of this study was to explore the possibility of disposing of fly ash in soil more acceptable with a simultaneous treatment with a polymeric soil conditioner (Wallace and Wallace 1986), so that the high levels of fly ash do not cause the physical properties of soil to deteriorate, as has been observed when high rates of fly ash are supplied to soil (Chang and others 1977; Parker and others 1978).

We grew wheat (Triticum aestivum L. ev. INIA66R) in a calcareous clay soil, a Torrifluvents from Imperial Valley, California, on containers in a glasshouse. The soil was amended with 450 kg ha^{-1} anionic polyacrylamide and 748 mg ha^{-1} of coal fly ash in factorial combination. Both amendments increased the vegetative yield of the wheat when applied singly, and when they were applied together the effect was sequentially additive (table 4).

Table 4--Vegetative yield of INIA66R wheat grown 19 d in a calcareous clay with and without a polyacrylamide (PAM) and with and without fly ash in factorial combination

Soil treatments	Dry weight mg plant^{-1}	Relative yield	Calculated relative yield
Control	28.5	1.00	--
450 kg ha^{-1} PAM	33.3	1.31	--
748 mg ha^{-1} fly ash	36.4	1.43	--
PAM + fly ash	49.6	1.95	1.87[1]
LSD 0.05			

[1] The combined effect appears to be sequentially additive because the product of 1.31 x 1.43 is very near the actual response for plants grown with both PAM and fly ash (1.95 versus 1.87).

Without the polyacrylamide, soil was compacted. Large quantities of waste fly ash can be disposed of with little or no environmental hazard through high-level application to land with simultaneous use of a polymer soil conditioner to maintain acceptable physical properties of soil.

CONCLUSIONS

1. Cost savings with more effective soil preparation can be achieved when polymeric soil conditioners are included in land reclamation projects.
2. Soil aggregate stability can be achieved for several years without simultaneous addition of extremely large quantities of organic amendments--modest quantities of organic amendments will do just as well as will large quantities as there are synergistic effects if applied with polymeric soil conditioners.
3. Use of polymeric soil conditioners can help overcome most of the problems related to loss of topsoil. Water penetration can be made to be satisfactory. Soil erosion can be minimized and even completely avoided. Soil becomes well aerated, and plants do better due to improved root growth.
4. Soils that drain very poorly due to such conditions as sodicity and excess salinity can be made to drain so that the reclamation process can be completed more rapidly and more efficiently than otherwise possible.
5. Polymeric soil conditioners can be important tools in the management of waste products that can be incorporated into soil in reclamation projects or of waste products for which land disposal is possible. Coal fly ash, mine tailings, and sewage sludge are examples.
6. New polymers are available for soil conditioning that are much better than those in use 35 years ago. Excellent soil preparation can be achieved with as little as 0.5% of the rates of the polymers in use then. Results are now better, and the economics is very favorable.
7. The most useful of the new polymers has been in investigation and use for the past five years.
8. The polymeric soil conditioners will improve any soil that contains some clay. The soil may be acid, neutral, or basic.
9. Soil tests are available which can predict need for and response to the polymeric soil conditioners. Soils laboratories in the past have tested soils primarily for their nutrient needs, but now it is possible to also test them for possible improvement of physical properties of soils.

REFERENCES

Aldrich, D. C., Jr.: Schoonover, W. R. 1951. Gypsum and other sulfur materials for soil conditioning. Calif. Agric. Exp. Stn. Circ. #403.

Allison, L. E. 1952. Effect of synthetic polyelectrolytes on the structure of saline and alkali soils. Soil Science 73: 443-454.

Allison, L. E.; Moore, D. C. 1956. Effect of VAMA and HPAN soil conditioners on aggregation, surface crusting, and moisture retention in alkali soils. Soil Science Society of America Proceedings 20: 143-146.

Azzam, Reda A. I. 1980. Agricultural polymers: Polyacrylamide preparation, application, and prospects in soil conditioning. Communications in Soil Science and Plant Analysis 11: 767-834.

Azzam, Reda A. I. 1985. Tailoring polymeric gels for soil reclamation and hydroponics. Communications in Soil Science and Plant Analysis 16: 1123-1138.

Babu, Suresh P., ed. 1975. Trace elements in fuel. Symposium American Chemical Society, 30 August 1973, Chicago, Illinois. Advances in chemistry series No. 141, American Chemical Society, Washington, D.C.

Barrada, Y. 1972. The role of the joint FAO/IAEA division of atomic energy in food and agriculture in improving water and fertilizer use efficiency. In: DeBoodt, M. E., ed. Symposium on fundamentals of soil conditioning proceedings; 17-21 April 1972; Ghent, Belgium, 37: 1035-1045.

Bear, Firman E. 1952. Synthetic soil conditioners. Soil Science 73: 419-492 (Special Issue).

Black, Charles G.; Adams, M. K. eds. Saving the soil. Science Food Agriculture 2: 2-8.

Bond, Richard G.; Straub, Conrad P.; Prober, Richard, eds. 1972. Handbook of environmental control, vol. 1: Air Pollution. CRS Press, Cleveland, Ohio.

Chang, A. C.; Lund, Lanny J.; Page, Albert L.; Warnek, J. E. 1977. Physical properties of fly ash-amended soils. Journal of Environmental Quality 6: 276-270.

Chepi, W. S. 1954. The effect of synthetic conditioners on some phases of soil structure and erodibility by wind. Soil Science Society of America Proceedings 18: 386-391.

Crosson, P. R.; Stout, A. T. 1984. Productivity effects of cropland erosion in the United States. Journal of Environmental Quality 13: 655-656.

Faber, J. W. 1976. U.S. overview of ash production and utilization. Proceedings 4th International Ash Utilization Symposium, 24-25 March 1976. ERDA Report MERC/SP-76/4, Morgantown Energy Research Center.

Ferguson, R. B.; Frischknecht, Neal C. 1983. Revegetating processed oil shale in the upper mountain-brush zone of Colorado. USDA Forest Service Research Paper INT-321. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Gupta, R. K.; Bhumbla, D. K.; Abrol, L. P. 1984. Effect of sodicity, pH, organic matter, and calcium carbonate on the disperson behavior of soils. Soil Science 137: 245-251.

Henderson, J. C.; Hensley, D. L. 1986. Efficacy of a hydrophilic gel as a transplant aid. Hort Science 21: 991-992.

Hodgson, L.; Dyer, D.; Brown, D. A. 1982. Neutralization and dissolution of high-calcium fly ash. Journal of Environmental Quality. 11: 93-98.

Jastrow, Judy D.; Zimmerman, C. A.; Dvorak, A. J.; Hinchman, R. R. 1981. Plant growth and trace-element uptake on acidic coal refuse amended with lime or fly ash. Journal of Environmental Quality 10: 154-160.

Kelley, Walter P. 1937. The reclamation of alkali soils. California Agricultural Experiment Station Bulletin No. 617.

Kemper, W. D.; Rosenau, R.; Nelson, Sheldon D. 1985. Gas displacement and aggregate stability of soils. Soil Science Society of America Journal 49: 25-28.

Khamraev, S. S.; Artykbaeva, Kh.; Nizamova, F.; Aklmedova, V. 1983. Leaching of salts from takyr soils conditioned by amide-containing polyelectrolytes. Uzb. Kim. Zh. 4: 16-20 (Russian) Chemical Abstracts 99: 138730.

Martens, D. C.; Beahm, B. R. 1978. Chemical effects on plant growth of fly ash incorporation into soil. In: Adriano, D. C.; Brisbin, I. L., Jr. eds. Proceedings of Symposium, 28 April to 1 May 1976, Augusta, GA.; Savannah River Ecology Lab, University of Georgia, Athens, pp. 637-644.

Oades, J. W. 1984. Soil organic matter and structural stability. Mechanisms and implications for management. Plant Soil 76: 319-338.

Parker, D. G.; Thornton, S. I.; Cheng, C. W. 1978. Permeability of fly ash-stabilized soils. Proceedings of Conference Geotech, Pract. Disposal Solid Waste Matter, 1977, ASCE, New York, pp. 63-70.

Phung, H. T.; Lund, Lanny J.; Page, Albert L. 1978. Potential use of fly ash as a liming material. In: Adriano, D. C.; Brisbin, I. L., Jr. eds. Proceedings of Symposium, 28 April-1 May 1976, Augusta, GA.; Savannah River Ecology Lab., University of Georgia, Athens, pp. 504-515.

Quastel, J. H. 1954. Soil conditioners. Annual Review of Plant Physiology 5: 75-92.

Richards, L. A. ed. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No. 60.

Terman, G. L., Kilmer, Victor L.; Hunt, C. M.; Buchnan, W. 1978. Fluidized bed boiler waste as a source of nutrients and lime. Journal of Environmental Quality 7: 147-150.

Wallace, Arthur; Nelson, Sheldon D. eds. 1986. Soil Conditioners. Soil Science 141: 311-397.

Wallace, Arthur; Wallace, Garn A. 1986. Enhancement of the effect of coal fly ash by a polyacrylamide soil conditioner on growth of wheat. Soil Science 141: 387-389.

Wallace, Arthur; Wallace, Garn A.; Abou-Zamzam, Ahmed M. 1986. Amelioration of sodic soils with polymers. Soil Science 141: 359-362.

Wallace, Garn A.; Wallace, Arthur. 1986. Control of soil erosion by polymeric soil conditioners. 141: 363-367.

CREATING RIPARIAN WILDLIFE HABITAT ALONG A COLUMBIA RIVER IMPOUNDMENT IN NORTHCENTRAL WASHINGTON

Robert G. Carson and Paul J. Edgerton

ABSTRACT: Irrigated riparian plantings totaling 37.5 ha were developed to compensate for habitats lost as the result of an increase in the operating level of Rufus Woods Lake. Twenty-four species of shrubs and trees were planted to provide forage and cover for wildlife. Soil characteristics, deer browsing, grass competition, and individual species' moisture needs have influenced development of the plantings.

INTRODUCTION

During February 1981, the U.S. Army Corps of Engineers (COE) implemented a 3-m pool rise on Rufus Woods Lake (RWL), an impoundment of the Columbia River in northcentral Washington (fig. 1). The purpose of the pool rise was to provide additional electrical generating capacity. As a result, 223 ha of land were inundated, including 47 ha of riparian habitat along the perimeter of the lake (Tabor and others 1980).

Under the authority of the Fish and Wildlife Coordination Act of 1958 (Public Law 85-624), the COE mitigated for wildlife losses which resulted from the 1981 rise. Studies were conducted prior to the pool rise (Erickson and others 1977) to determine the kinds and extent of habitats which would be flooded and to survey the wildlife populations using those habitats. A committee consisting of representatives of the COE, U.S. Fish and Wildlife Service, Washington State Department of Game, and the Colville Confederated Tribes then prepared a mitigation plan (U.S. Army Corps of Engineers 1980) which was funded and implemented by the COE. A major component of the plan was the replacement of inundated riparian habitat through the planting and irrigation of riparian tree and shrub species on upland areas adjacent to the lake. Other features of the mitigation plan not addressed in this paper included the construction of islands for waterfowl nesting and brood rearing, goose nesting structures, goose feeding pastures, raptor perch poles, and the fencing of some remaining riparian areas along the river to exclude livestock grazing.

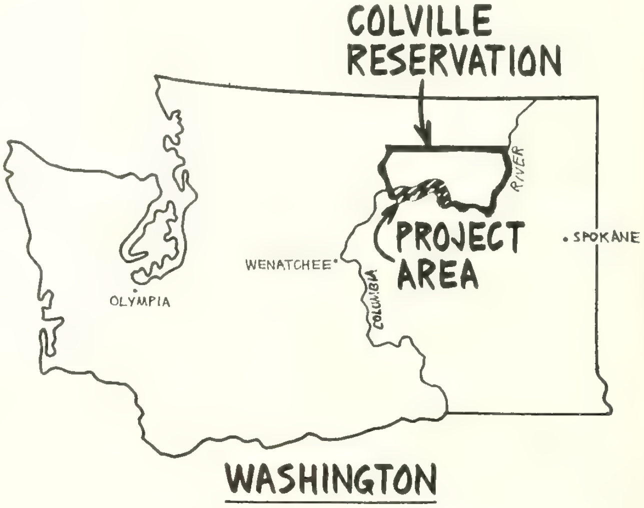

Figure 1--Location of the riparian habitat development project area along the Columbia River in Washington.

This paper describes an important operational project to develop and maintain riparian habitat through irrigation and planting. Some of the management concerns that have surfaced during the project underscore our need to better understand the ecophysiology of commonly planted wildland shrubs and trees in order to better match them to site factors and management treatments. Permission was granted by the COE, Seattle District, to publish the information contained in this paper.

PROJECT AREA DESCRIPTION

RWL is an impoundment of the Columbia River formed by Chief Joseph Dam. The reservoir extends 83 km, reaching almost to the base of Grand Coulee Dam. Width of the lake ranges from 150 m to 800 m, and maximum pool elevation is 291 m. Soils of the project area were derived

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Robert G. Carson was a Wildlife Biologist with the Colville Confederated Tribes, Bridgeport, WA, from 1985-1987. Currently he is a Wildlife Biologist with Beak Consultants Incorporated, Portland, OR. Paul J. Edgerton is Supervisory Ecologist and Project Leader at the Forestry Sciences Laboratory, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Wenatchee, WA.

from weathered granite, glacial outwash and alluvium, with loess deposits on the surface (Beieler 1981).

The climate is characterized by hot, dry summers and cool, dry winters. Average temperatures at the Chief Joseph Dam weather station range from -4 to 0 °C during December through February, and 19 to 23 °C during June through August. Considerable diurnal variation in temperature occurs in all seasons with annual extremes ranging from -23 to 46 °C.

Average annual precipitation is approximately 25 cm. Average monthly precipitation during the summer is 1.40 cm. Monthly winter precipitation averages 3.15 cm with the majority occurring as snowfall.

The vegetation in the project area is typical of arid grass-shrub communities found throughout much of eastern Washington and Oregon (Daubenmire 1970, Daubenmire and Daubenmire 1968). Large areas adjacent to the reservoir are dominated by basin big sagebrush (*Artemisia tridentata tridentata*)[1] and antelope bitterbrush (*Purshia tridentata*) communities. Basin big sagebrush occurs on deep, moderately drained soils at low to mid elevations while bitterbrush occurs on deep, sandy or gravelly soils at low elevations. The most extensive habitat types are big sagebrush/bluebunch wheatgrass (*Agropyron spicatum*), big sagebrush/needle-and-thread grass (*Stipa comata*), bitterbrush/bluebunch wheatgrass, and bitterbrush/needle-and-thread grass. The giant wildrye (*Elymus cinereus*)/saltgrass (*Distichlis stricta*) habitat type occurs on alkaline sites.

RIPARIAN HABITAT DEVELOPMENT

Construction of six irrigated riparian habitat development areas along RWL was initiated by the COE in 1982 and completed in early 1983. Each area was fenced to exclude livestock and existing vegetation was cleared using a rotary-chain mower. Depending on the size and configuration of each site, 5 to 24 irrigation circles (55 m average diameter) were constructed to utilize water pumped from RWL (fig. 2). The irrigation systems consisted of permanently mounted sprinkler heads on 1.83-m standpipes operated either individually or two at a time by either 20-horsepower or 40-horsepower submersible pumps. Water was applied at an average rate of 1.52 cm per hour. The area under irrigation at each site ranged from 1.9 to 10.9 ha with the entire project totaling 37.5 ha (table 1).

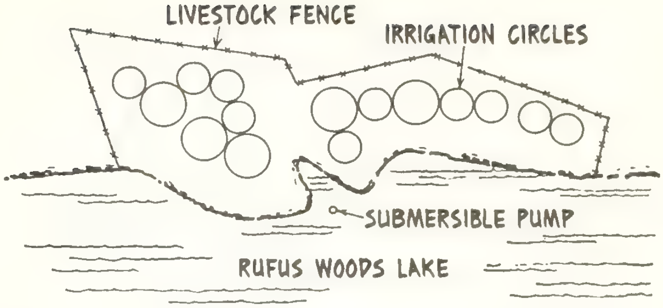

Figure 2--Typical layout of an irrigated riparian habitat area. Note that the irrigation circles vary in size.

Table 1--Area under irrigation at each of the six riparian habitat development sites

Site name	Area irrigated
	Hectares
Wells Flat	9.1
Brandts Landing	1.9
Arrowhead	7.3
Allen Bar	10.9
Site 12	4.6
Alameda Flat	3.7
Total	37.5

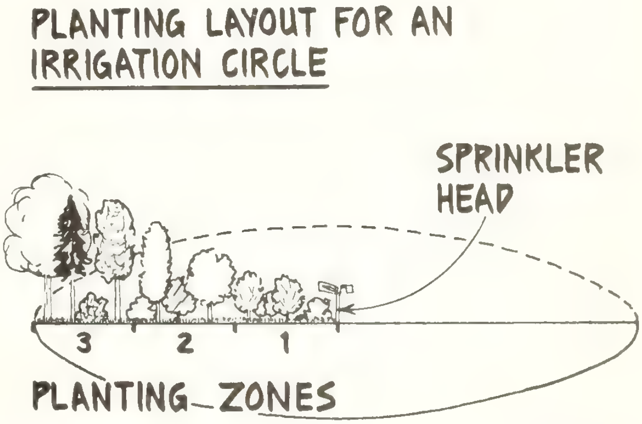

Figure 3--Typical cross-section of an irrigation circle showing the location of planting zones. The circles average 55 m in diameter.

Sherman big bluegrass (*Poa ampla*) and Durar hard fescue (*Festuca ovina duriuscula*) were seeded in the fall of 1982 to establish a dense grass stand that would prevent the establishment and spread of noxious weeds. Trees and shrubs were hand-planted during April and May of 1983 at a density of 3580/ha. The desired stocking at maturity was 1790/ha (assuming 50% mortality). One and 2-year-old containerized seedlings grown in 65-cc cells were planted in 0.25-m^2 areas scalped free of competing vegetation. A slow-release fertilizer tablet was inserted 3 cm away from the seedling roots.

Irrigation circles were divided into three concentric planting zones from the sprinkler head to the circle perimeter (fig. 3). Each zone encompassed approximately one-third of the irrigated area. Species were planted in specific zones according to expected maximum height at maturity. Low growing shrubs were planted closest to the sprinkler head, and trees and tall shrubs were planted closest to the perimeter. The purpose of this planting design was to ensure that all plants received a sufficient amount of water throughout the duration of the project.

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[1] Scientific and common names are from Garrison and others (1976) and Plummer and others (1977).

More than 100,000 seedlings, including three conifer species, five deciduous tree species, and 16 deciduous shrub species (table 2), were planted during the spring of 1983 to provide similar forage value and structural diversity to that of the inundated habitats. An additional 21,000 seedlings were planted during April 1984 to replace first-year mortality and to adequately stock areas missed during the initial planting.

Irrigation provided supplemental water throughout the typically warm, dry growing season. During the 1983-86 seasons, approximately 3.5 cm of water were applied weekly beginning about the third week of April and continuing through late August (fig. 4). Irrigation was terminated in late August to allow gradual drying of the soil and to induce dormancy prior to the onset of harsh, winter temperatures.

Table 2--Tree and shrub species planted during 1983 and 1984 in irrigated riparian habitats developed along Rufus Woods Lake, Washington

Common and scientific names	Number planted
Coniferous trees:	
Ponderosa pine (*Pinus ponderosa*)	2,645
Rocky Mountain juniper (*Juniperus scopulorum*)	2,615
Colorado blue spruce (*Picea pungens*)	2,369
Subtotal	7,629
Deciduous trees:	
Russian-olive (*Elaeagnus angustifolia*)	5,506
Black locust (*Robinia pseudo-acacia*)	2,395
Black cottonwood (*Populus trichocarpa*)	1,487
Water birch (*Betula occidentalis*)	1,291
Mulberry (*Morus* sp.)	485
Subtotal	11,164
Dedicuous shrubs:	
Native rose (*Rosa* sp.)	23,372
Common snowberry (*Symphoricarpos albus*)	18,995
Golden currant (*Ribes aureum*)	12,830
Blueberry elder (*Sambucus cerulea*)	12,035
Smooth sumac (*Rhus glabra*)	8,910
Red-osier dogwood (*Cornus stolonifera*)	7,250
Black hawthorn (*Crataegus douglasii*)	6,779
Himalayan blackberry (*Rubus discolor*)	5,410
Serviceberry (*Amelanchier alnifolia*)	3,237
Huckleberry (*Vaccinium* sp.)	1,085
Skunkbrush sumac (*Rhus trilobata*)	620
Western virginsbower (*Clematis ligusticifolia*)	620
Buffaloberry (*Shepherdia* sp.)	575
Common chokecherry (*Prunus virginiana*)	500
American plum (*Prunus americana*)	320
Bush cinquefoil (*Potentilla fruticosa*)	135
Subtotal	102,673
Total all species	121,466

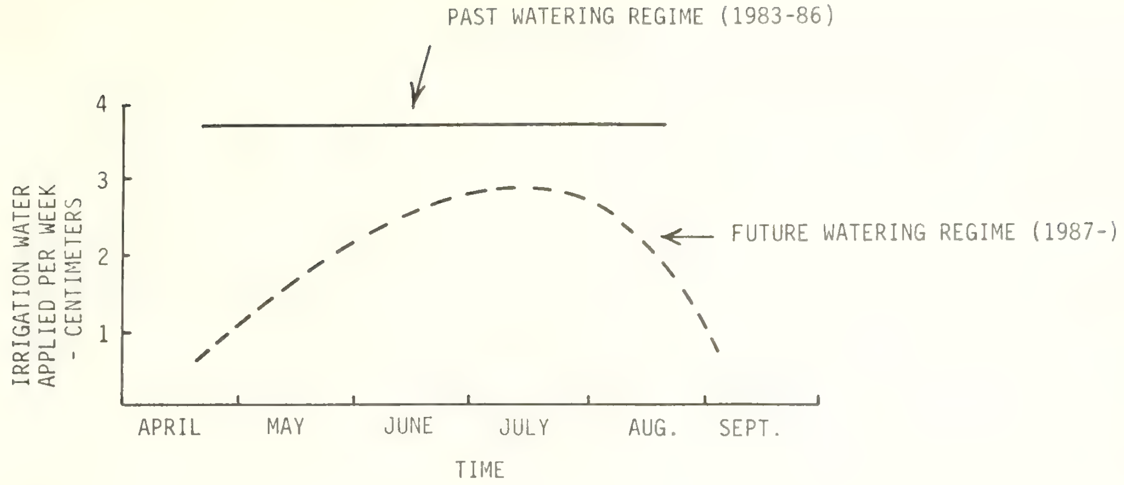

Figure 4--Past and present watering regime showing the seasonal distribution of the amount of irrigation at an average site.

RESULTS AND DISCUSSION

The results of studies currently in progress to provide detailed information on survival and growth of individual species are not yet available. However, based on extensive observations, we estimate that overall survival of shrubs and trees after five growing seasons is approximately 80 percent. In some areas, there has been virtually no mortality, whereas in localized areas where alkalinity is high or other soil characteristics are unfavorable, survival has been poor. Growth rates of shrubs and trees have varied greatly both between and within the six irrigated areas, and between species. Four major factors appear to be affecting growth rates: soil characteristics, water requirements of individual species, grass competition, and deer browsing. There appears to be considerable interaction among these factors, thus complicating the assessment of their individual effects.

Soil Characteristics

Extensive soil testing was conducted within the six irrigated riparian habitat areas during 1986. Physical and chemical soil characteristics of areas where excellent shrub and tree growth occurred were used as baselines to evaluate those areas where growth was poor. Although considerable variation occurred between sites, poor growth was generally correlated with deficiencies of important soil nutrients such as nitrogen, potassium, or sulfur. There is concern that continued irrigation of these relatively infertile soils may be leaching nutrients from the root zone, particularly on coarse, sandy soils. Test applications of fertilizer are proposed for the fall of 1987. If positive responses are observed, large-scale fertilizer applications may be implemented in 1988.

Poor plant growth in areas with adequate soil nutrient levels appeared to be related to restrictive physical properties of the soil. Robust, fast-growing plants were often found growing in back-filled areas which had been excavated when the irrigation system was installed. Plants growing adjacent to these areas often showed poor growth rates which we believe were due to some physical limitation of the soil, such as compaction by construction equipment or the presence of a hardpan, rather than a nutritional deficiency.

Grass Competition

The seeded grass cover has become well established with lush, dense foliage and a dense root mass. Competition with this grass cover for soil nutrients is believed to be adversely affecting growth rates of the planted shrubs and trees, especially among the slower growing species. At many sites where soil analyses indicate favorable soil conditions, shrubs and trees are growing poorly amidst vigorously growing grasses. In these instances, it appears that grasses are out-competing the shrubs and trees for nutrients, and to a lesser extent, are reducing available sunlight.

Benefits of the dense grass cover may outweigh competitive effects. The grass cover provides habitat for several species of small mammals and birds and has effectively prevented the establishment of noxious weeds which are of great concern to agriculturalists and public land managers in the area. Numerous small areas which were missed during grass seeding operations in 1983 were rapidly colonized by annual and perennial forbs such as Canada thistle (*Cirsium arvense*), horseweed (*Conyza canadensis*), yellow sweetclover (*Melilotus alba*), and tumblemustard (*Sisymbrium altissimum*). These plants compete agressively for nutrients, moisture and sunlight and, in areas where they were particularly dense, may have contributed to the mortality of some tree and shrub seedlings during the first growing season. In areas that were seeded with grasses, however, these noxious weeds were uncommon by the end of the second growing season. In most areas the grasses have not significantly affected shrub and tree growth, and have generally been beneficial to the development of the riparian habitats.

Test applications of Kerb herbicide (3,5-dichloro-N-benzamide) were made in November 1986 in localized areas where the seeded grasses appeared to be adversely affecting tree and shrub growth. Kerb selectively kills grass but does not affect broadleaf plants or conifers. Favorable results were observed during the spring of 1987 with nearly 100-percent grass kill within the 0.75-m diameter treated spots. The herbicide did not appear to be toxic to any of the planted trees and shrubs. We anticipate that the treated plants will not only benefit from the release from competition, but also from nutrients and organic matter added to the soil as the foliage and roots of the treated grasses decompose.

Water Requirements

The 24 species of shrubs and trees planted are native to environments with a wide range of moisture regimes. Ponderosa pine, serviceberry, snowberry and several other species are native to mesic, upland sites within the project area. Accordingly, they require much less supplemental water than true riparian species such as water birch or black cottonwood.

Neither the effects of overwatering nor the minimum water requirements for many of the planted tree and shrub species are well understood. Since the time of planting in 1983, all species have been watered at the same rate throughout the growing season. This practice has been sufficient to allow establishment and growth of the most water-loving species without any obvious negative effects on those species that require less water. It would be beneficial, nevertheless, to develop a watering regime that promotes optimum growth of most species without overwatering. It is likely that overwatering reduces growth rates by leaching soil nutrients from the surface soil horizons. In addition, excessive watering increases manpower and equipment maintenance costs.

Beginning with the 1987 season, a watering regime was implemented that was responsive to the seasonal pattern of available soil moisture and to the peak moisture demands of the shrubs and trees. Soil moisture levels were monitored closely and water was applied to just saturate the soil profile. Between irrigations, the soil was allowed to dry almost to the point of causing moisture stress. This resulted in approximately a 35-percent decrease in the amount of irrigation applied. The watering schedule throughout the irrigation season was also altered, with less water applied in spring when the soil profile was charged from snowmelt, and more applied in mid-summer when evapotranspiration was greatest (fig. 4). This watering regime is proposed for future years to reduce nutrient leaching and promote deeper rooting of shrubs and trees.

Deer Browsing

Deer browsing has been a major factor affecting growth and survival of the planted shrubs and trees at several sites. Mule deer (Odocoileus hemionus) utilize most of the areas on a yearlong basis, with greatest concentrations occurring during wintering periods. Unlike the other factors previously discussed, deer browsing is easily recognized and measured, and can be controlled by fencing and other means.

From 1983 to 1986, yearlong heavy browsing significantly affected the development of shrubs and trees at Allen Bar, while the other five riparian habitat development areas received little to moderate browsing pressure. By 1986, few plants at Allen Bar were taller than 20-25 cm, while average heights at other sites probably exceeded 100 cm. Species receiving the heaviest use, such as red-osier dogwood, black cottonwood, black locust, and water birch, experienced considerable mortality (> 50%). To prevent continued mortality and deterioration of habitat quality, a temporary deer-proof fence was constructed around the area in 1986. In addition, the site was replanted in April 1987 with 14,000 tree and shrub seedlings to compensate for mortality incurred during 1983 to 1986. Surviving shrubs and trees from the original planting have exhibited excellent growth since deer have been excluded. The fence will be removed in 5-10 years when the plants are large enough to withstand the impact of heavy deer browsing.

Promising Species

After five growing seasons, 11 species have been quite successful based on their survival and growth, and use by wildlife for forage or cover. Trees include ponderosa pine, Rocky Mountain juniper, black cottonwood, black locust, Russian olive, and water birch; shrubs are golden currant, Himalayan blackberry, rose, common snowberry and red-osier dogwood. Other species are likely to become more important as they become better established or respond to management practices such as fertilization, release from competition, or protection from deer.

CONCLUSIONS AND RECOMMENDATIONS

After five growing seasons, a variety of trees and shrubs have become established in the riparian habitat development areas. They include true riparian species such as water birch, and others such as black locust and Russian olive that require less moisture but cannot grow satisfactorily in the arid shrub-steppe environment without supplemental water. Although the plantings are still developing, the most successful areas (and species) have already begun to emulate the structure and function of the riparian habitats they were developed to replace.

Numerous wildlife species are using the plantings, including mule deer, waterfowl, upland game birds, song birds, small mammals, and reptiles. A variety of raptors perch and capture prey in the plantings. As the riparian habitats continue to develop, utilization by wildlife is expected to increase.

As a result of the experience gained to date from this project, we recommend that several important factors be considered in the development of similar projects to maximize their present and future value to wildlife. First is size and location of wildlife habitat management areas in relation to existing, planned, and potential adjacent agricultural developments. Along RWL, the land surrounding several of the irrigated sites has been converted from shrub-steppe vegetation to intensively managed agricultural fields and fruit orchards. This has precluded the use of these areas by many wildlife species that either avoid human activity or are excluded by fences or other physical barriers.

The spatial distribution of replacement habitat is also an important consideration. The number of hectares of riparian habitat that were created by this project closely approximates the number that were inundated by the 1981 pool rise. However, the distribution of the riparian habitat that was inundated (long, narrow bands along many kilometers of river shoreline) is vastly different from that which was developed for mitigation (several large blocks). This may have either positive or negative impacts on wildlife depending on habitat use patterns and the size of the home range or territory required by individual species.

Next is the need to lessen or exclude grazing and browsing pressure on young plants to allow establishment. This may require short-term fencing where seasonal livestock grazing or wintering concentrations of big game are likely to suppress growth or cause unacceptable seedling mortality.

It is also important that the wide range of growth requirements of the various species planted be considered when developing maintenance procedures for this kind of project. This includes the formulation and close monitoring of an appropriate irrigation schedule, application of supplemental nutrients (fertilization), and mechanical or chemical control of competing grasses and forbs. In some situations, carefully controlled grazing and prescribed fire may be appropriate strategies to suppress competition.

Finally, it is critical that an adequately funded monitoring program be incorporated into the project. This will help to identify problems that may arise and will ensure that project goals are being met. A monitoring program will also allow people involved in the planning or operation of similar projects to learn from others' successes and failures. The project described in this paper has been an effective but costly means of migitating for habitat losses along RWL. Where limited funding is available, however, managers and biologists should consider alternative strategies such as shoreline plantings, protection of existing riparian communities from grazing, development or enhancement of riparian habitat around springs and along small streams, and the installation of other less expensive supplemental watering systems.

REFERENCES

Beieler, Vern E. 1981. Soil survey of Douglas County, Washington. National Cooperative Soil Survey, U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the Washington State University Agricultural Research Center, Pullman, WA. 180 p.

Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agricultural Experiment Station Tech. Bull. 62. Pullman, WA: Washington State University. 131 p.

Daubenmire, R.; Daubenmire, Jean B. 1968. Forest vegetation of eastern Washington and northern Idaho. Washington Agricultural Experiment Station Tech. Bull. 60. Pullman, WA: Washington State University. 104 p.

Erickson, A. W.; Stober, Q. J.; Brueggeman, J. J.; Knight, R. L. 1977. An assessment of the impact on the wildlife and fisheries resource of Rufus Woods Reservoir expected from the raising of Chief Joseph Dam from 946 to 956 ft. m.s.l. Report by the College of Fisheries, University of Washington, Seattle, WA 455 p. + appendices.

Garrison, G. A.; Skovlin, J. M.; Poulton, C. E.; Winward, A. H. 1976. Northwest plant names and symbols for ecosystem inventory and analysis. 4th ed. Gen. Tech. Rep. PNW-46. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 263 p.

Plummer, A. Perry; Monsen, Steven B.; Stevens, Richard. 1977. Intermountain range plant names and symbols. Gen. Tech. Rep. INT-38. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

Tabor, James; Thompson, Bruce; Turner, Clarence; Stocker, Randall; Detrick, Chris; Howerton, Jack. 1980. Study of impacts of project modification and river regulation on riparian habitats and associated wildlife along the Columbia River. Report by the Washington State Department of Game, Habitat Management Division, Olympia, WA. 770 p.

U.S. Army Corps of Engineers. 1980. Chief Joseph Dam additional units, Columbia River, Washington, wildlife and threatened species mitigation. Design Memorandum 52. Department of the Army, Seattle District, Corps of Engineers, Seattle, WA.

USE OF NATIVE SHRUBS ON STRIP-MINED LANDS IN THE HUMID EAST

H. Glenn Hughes

ABSTRACT: Past and present factors limiting shrub use on mined lands are reviewed. Competing herbaceous vegetation on strip-mined sites in Pennsylvania hindered woody plant growth and survival. Reclaiming sites of high productive potential with shrubs valuable to wildlife requires reduction of herbaceous competition. One-time herbicide treatments generally do not work, multiple herbicide applications are economically unfeasible in most situations. Seeding or planting shrubs in strips devoid of herbaceous species may increase shrub survival by decreasing competition.

INTRODUCTION

Reclaiming strip-mined areas represents an opportunity for the establishment of shrubs and other vegetation as wildlife habitat because whole ecosystems are constructed. However, strip-mined areas contain a variety of site characteristics, due principally to the evolution of reclamation laws which began around World War II. Early reclamation efforts were concerned primarily with steep slopes, highwalls, and physical hazards, but as laws and regulations progressed more attention was focused on revegetation.

In 1977 the Federal Government passed legislation establishing minimum requirements for reclamation of mined lands (Leedy and others 1981). This legislation requires, among other things, the separation and replacement of topsoil, restoration of land to approximate original countours, and establishment of perennial vegetation. While this legislation reduced soil erosion and sedimentation, the use of perennial woody species, including shrubs, has decreased. Meeting bond requirements by achieving a certain percentage of perennial plant cover is easier with herbaceous species than with woody species (Vogel 1979). Additionally, herbaceous vegetation used on mined sites is typically more aggressive than woody species and hinders woody plant growth and survival (Davidson and others 1984). Also, soil compaction from grading is detrimental to woody perennials (Chapman 1967) and can restrict root growth and development (Spaniol 1982).

In this paper I examine the use of shrubs on reclaimed sites, the factors limiting shrub growth and survival, ways to increase revegetation success using shrubs, and the future role of shrubs for strip-mining reclamation. Due to the drastic differences between past and present mine site conditions, revegetation failures of the past may not occur under present conditions. Likewise, revegetation successes of the past may not be repeatable.

FACTORS LIMITING SHRUB USE

Historically, site characteristics such as acidity, fertility, or soil depth have limited the development of vegetation on eastern mined sites (USDA Soil Conservation Service 1978). Consequently, species which survived on these sites (and recommended for reclamation purposes) were those which could tolerate adverse site conditions. Shrubs typical of this category include bristly locust (Robinia fertilis), autumn olive (Elaeagnus umbellata), multiflora rose (Rosa multiflora), Japanese barberry (Berberis thunbergii), Japanese honeysuckle (Lonicera japonica), and tartarian honeysuckle (L. tatarica) (Leedy and others 1981). Primarily exotics, some of these species escaped into adjacent areas, proving difficult to control and decreasing site productivity (i.e., multiflora rose, Japanese honeysuckle and, to a lesser extent, autumn olive). Studies using native shrubs have not been promising. In a guide compiled by the USDA Soil Conservation Service (1978), few of the native shrub species extensively tested (10+ sites) performed well. Other factors can also limit the use of shrubs on strip-mined lands such as browsing by wildlife, particularly deer and rabbits, seed availability and germination, and slow growth rates.

With the advent of the 1977 legislation, liming and fertilization became common practices to reduce acidity and increase nutrient levels. Additionally, regulations required the establishment of 70% perennial plant cover by the mining company for release of its bonding obligation. The primary objective of current reclamation practice is the establishment of perennial herbaceous species such as K-31 tall fescue (Festuca arundinacea), birdsfoot trefoil (Lotus corniculatus), and crownvetch (Coronilla varia) which rapidly meet the 70% cover requirement. Shrubs or trees are a secondary consideration, if planted at all. In addition, species such as tall fescue may suppress slow growing woody species (Leedy and others 1981). Consequently, over the past 10-15 years, factors limiting the use of shrubs possibly changed from site attributes (low pH) to increased herbaceous competition.

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H. Glenn Hughes is Assistant Professor of Wildlife Technology, DuBois Campus, Pennsylvania State University, DuBois, PA 15801

Currently, species recommendations for mine reclamation in the Eastern United States are based largely on tolerance to infertile and acid sites (USDA Soil Conservation Service 1978). Studies on rights-of-way have indicated that herbaceous vegetation effectively controls shrub growth and survival (USDA Plant Materials Center 1978, 1985). However, similar information describing how shrubs respond to herbaceous competition on strip-mined sites, and how to best alleviate competition, is not widely available. Therefore, in 1984 I began studies to evaluate shrub survival under various levels of herbaceous competition.

NATIVE SHRUB SURVIVAL

The first study examined 2 native shrubs, silky dogwood (Cornus amomum) and northern arrowwood (Viburnum recognitum), as potential shrub species for use on strip-mined sites and the effects of herbaceous competition and deer browsing on plant survival. The effects of 3 levels of herbaceous competition (low, medium, and high) on shrub growth and survival were tested.

The high level of herbaceous competition was produced by planting shrubs onto a site already supporting K-31 tall fescue and birdsfoot trefoil. The medium level of herbaceous competition was produced by spot application of a non-selective herbicide (Roundup brand of glyphosate) on a site supporting herbaceous vegetation and planting shrubs in the bare spots created by the herbicide. The low level of herbaceous competition was produced by planting seedlings immediately after herbaceous species were seeded. Exclosures were erected on approximately 20% of each area to evaluate deer impact.

The effects of herbaceous competition and species on shrub survival after two years were analyzed with log-linear analysis of survival probabilities (SAS 1982: 257-285). Although shrub survival was high after 1 growing season (78-98%), data after the second (and drier) growing seasons indicated that survival dropped considerably (table 1). This resulted from poorer growing conditions (less rainfall) in 1985 and increased herbaceous cover in those treatments either sprayed or planted at the time of seeding. Both species and level of herbaceous competition affected survival after two growing seasons (Chi-square = 78.4 and 54.4, respectively, $p<.01$). However, more recent data indicate that survival on most treatments is now below 50%. Apparently, control of herbaceous competition is needed for several years to ensure adequate survival of these shrubs.

Table 1--Percent survival of silky dogwood and northern arrowwood under 3 levels of herbaceous competition at 1 and 2 growing seasons after planting (1984/85)

	Herbaceous Competition		
Species	Low	Medium	High
Silky dogwood	70	56	48
Northern arrowwood	76	81	74

It was evident at the end of the 1984 growing season that the herbaceous vegetation at all 3 treatment levels was competing with the shrubs for water and nutrients. Spot application of herbicide, though reducing herbaceous vegetation temporarily, did not prevent herbaceous species, particularly clover, from invading the sprayed area later in the growing season. Likewise, where shrubs and herbaceous vegetation were planted concurrently, herbaceous vegetation became established quickly.

DIRECT SEEDING

Due to the rapid establishment of herbaceous vegetation and subsequent effects of competition on shrubs in the above study, another study was begun in 1985 to examine alternative ways to reduce herbaceous competition. Herbaceous species are frequently planted by drilling. This technique was modified to reduce competing herbaceous vegetation and enhance growth and survival of woody species. Instead of spraying existing herbaceous vegetation or planting seedlings into freshly seeded sites, the intent was to test a system where both herbaceous and woody species could be seeded in one pass. To decrease competition, the seeding procedure was modified to seed woody species in one port and herbaceous species in the other ports of the Tye Pasture Pleaser planting drill. This required plugging certain ports in the drill to create a bare strip in the herbaceous seeding (table 2).

Scarified black locust (Robinia pseudoacacia) seeds were planted in the bare strips, thus reducing the effects of herbaceous competition. Black locust, though not a shrub, was used because it is perhaps the most successful and commonly used woody species in Pennsylvania on strip-mined sites and could be expected to survive relatively well. Any differences in survival or growth would then be due to the planting procedure.

Table 2--Seeding design used on the Tye Pasture Pleaser to achieve high, medium and low levels of herbaceous competition when seeding herbaceous and woody species[1]

Level of competition	Seed box	Port number 1	2	3	4	5	6	7	8	9	10
High	Large	[2]0	0	0	0	0	0	0	0	0	-
	Small	0	0	0	0	L	0	0	0	0	-
Medium	Large	0	0	0	0	-	0	0	0	0	-
	Small	0	0	0	0	L	0	0	0	0	-
Low	Large	0	0	0	-	-	-	0	0	0	-
	Small	0	0	0	-	L	-	0	0	0	-

[1] The large seed box contained tall fescue, and the small seed box the legume mixture and black locust.

[2] 0=open; L=locust; -=closed

The drill used was a 10-port Tye Pasture Pleaser, with the ports 20 cm apart. The large hopper seeded K-31 tall fescue at a rate of 56.0 kg/ha. The small (legume) hopper seeded both a herbaceous mixture and black locust. Birdsfoot trefoil was the main component of the herbaceous mixture (7.1 kg/ha). The legume seed box was modified to seed black locust in the #5 port and the herbaceous mixture in the other ports.

Three different planting treatments were tested. The treatments differed in the degree of competition between locust and herbaceous species. In the first treatment, no bare strip was created, thus K-31 tall fescue and black locust were seeded in the same row, creating direct competition between fescue and black locust. In the second treatment, herbaceous species were excluded from direct competition with locust by not planting fescue in the #5 port. In the third treatment, herbaceous species were excluded from the row in which locust was seeded (#5) and from adjacent rows (#'s 4 and 6). These treatments were achieved with only minor modifications to the drill, the principal modification being the construction of a "mini-hopper" around port no. 5 to contain the locust seeds.

Sixteen months after seeding, measurements were taken on plant height, canopy cover, and number of plants per 20 m strip. At this time the site met the requirements (70 percent plant cover) for bond release.

Direct competition between herbaceous species and black locust decreased the number of live plants per plot, average plant height, and canopy cover (table 3) (Hughes and Garthe, in press). Seedling height decreased with increasing herbaceous competition. Significant differences in seedling height were noted between low and high levels of competition, but the medium level of competition was not different from either the low or high level of competition. Canopy surface area, maximum crown diameter, and minimum crown diameter results paralleled those of plant height. The level of herbaceous competition affected locust survival. The number of locust seedlings present 16 months after planting dropped dramatically when there was direct competition between herbaceous and woody species. The number of plants per plot under low and medium levels of competition was 2.5 to 3 times greater than under the high level of competition.

Some states require that a certain number of trees or shrubs be established on a reclaimed area. Kentucky, for example, requires 1,976 trees/ha (Rafaill and Vogel 1978). In the current experiment, the low and medium levels of herbaceous competition meet this requirement (3,634 and 4,126 trees/ha, respectively). However, locust would have to be seeded in an additional port to achieve adequate stocking under the high level of herbaceous competition (currently 1,421 trees/ha).

These results demonstrate that even the most effective and widely used woody perennial is affected by herbaceous competition, but planting procedures can be designed to promote growth and survival of woody perennials. Seeding herbaceous and woody species in such a manner costs considerably less than planting seedlings and allows for an efficient mechanism to regulate competition between woody and herbaceous plants.

CONCLUSIONS

The future role of shrubs in reclamation in the East is uncertain. Shrubs such as bristly locust can and will be used on orphan mines with site limitations and little competing vegetation. However, the inherent low fertility limits productivity from a wildlife habitat standpoint. Lands which are mined, backfilled, graded, topsoiled, limed, fertilized, and seeded have a much higher productivity potential, but aggressive herbaceous vegetation limits shrub survival. Expecting shrubs less competitive than black locust to survive under high levels of herbaceous competition is unreasonable. Reducing competition for at least 2-3 years is required for the successful establishment of shrubs. Although this cannot be accomplished by a one-time application of herbicide, periodic herbicide application is possible, though economically unfeasible in most situations. Establishing shrubs by direct seeding has potential for reducing herbaceous/woody species competition.

REFERENCES

Chapman, A.G. 1967. How strip-land grading affects tree survival and growth. Publ. 29. Carbondale IL: Southern Illinois Univ., School of Agriculture. 34 p.

Table 3--Mean black locust growth and survival under low, medium, and high levels of herbaceous competition[1]

Level of Compet.	Plant height (cm)	Maximum canopy diam. (cm)	Minimum canopy diam. (cm)	Canopy surface area (cm^2)	Number trees/ plot
Low	49.9 (1.7) [2]a	28.1 (1.0) a	19.5 (1.4) a	435 (41) a	13.3 (1.5) a
Medium	41.3 (2.3) ab	24.2 (1.1) ab	18.3 (0.6) ab	351 (27) ab	15.1 (1.0) a
High	37.1 (4.7) b	20.8 (3.0) b	14.1 (2.0) b	260 (64) b	5.2 (1.0) b

[1] Numbers within parentheses are standard errors of the means.

[2] Numbers within a column followed by the same letter are not significantly different ($P<0.05$).

Davidson, W.H.; Hutnik, R.J.; Parr, D.E. 1984. Reforestation of mined land in the Northeastern and North-Central U.S. North. J. Appl. For. 1: 7-12.

Hughes. H.G.; Garthe. J.W. In press. Direct seeding of black locust reduces herbaceous competition. Landscape and Urban Planning.

Leedy, D.L.; Franklin, T.M.; Mason, W.T.; Cushwa, C.T. 1981. Coal surface mining reclamation and fish and wildlife relationships in the Eastern United States. Volume II. Opportunities and approaches for fish and wildlife planning and management in coal surface mining, reclamation and postmining land use. USDI FWS/OBS-80/25. Washington, D.C.: U.S. Department of Interior. 169 p.

Rafaill, B.L.; Vogel, W.G. 1978. A guide for vegetating surface-mined lands for wildlife in eastern Kentucky and West Virginia. USDI FWS/OBS-78/84. Washington D.C.: U.S. Department Of Interior. 89 p.

SAS users guide: Statistics, 1982 Edition. 1982. SAS Institute Inc., Cary, NC. 584 p.

Spaniol, J.A. 1982. Root and shoot growth of black walnut seedlings on topsoiled and non-topsoiled minesoils. In: Kolar, C.A.; Ashby, W.C., eds. Proceedings of 1982 Seminar on Post Mining Productivity with Trees; 1982 March 31-April 2; Carbondale, IL: Southern Illinois University: 41-50.

U.S. Department of Agriculture, Plant Materials Center, 1978. Annual Technical Report. U.S. Department of Agriculture, Soil Conservation Service. Big Flats, NY. 145 p.

U.S. Department of Agriculture, Plant Materials Center. 1985. Plant materials activities in the Northeast; 1985 Report. U.S. Department of Agriculture, Soil Conservation Service. Corning, NY. 17 p.

U.S. Department of Agriculture, Soil Conservation Service. 1978. Plant performance on surface coal mine spoil in Eastern United States. Tech. Pap. 155. Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service. 76 p.

Vogel, W.G. 1979. Are trees neglected plants for reclaimed surface mines? In: Hurlbutt, H.W.; Keller, E.C., eds. West Virginia Academy of Science: Proceedings; 1979 April 6; Athens WV: Concord College: 127-138.

Section 3—Ecophysiology

INFLUENCE OF STRESS HISTORY ON WATER USE PATTERNS OF HONEY MESQUITE

R.J. Ansley, P.W. Jacoby and B.K. Lawrence

ABSTRACT: Transpirational water loss by honey mesquite (Prosopis glandulosa Torr.) adversely affects watershed supply on over 23 million ha of Texas rangeland. The objective of this study was to determine response of this species to moisture availability following preconditioning to different levels of moisture stress. Twelve trees, located 20 km south of Vernon in North Central Texas, were manipulated through the use of drip irrigation and subcanopy rain shelters to three levels of moisture stress: low (LS), control (CT), and high (HS). The root system of each tree was containerized with a 2m deep vertical barrier to eliminate competition from neighboring trees and prevent lateral flow of soil moisture into sheltered areas. Predawn leaf water potentials (PWP) were -1.6, -1.2 and -1.0 MPa on June 27, and -2.1, -1.7 and -1.4 MP on July 28, 1986 for HS, CT and LS trees, respectively. Diurnal stomatal conductance (CS) was greatest on the LS trees and least on the HS trees on both dates. Following watering of all trees (equivalent to 40mm precipitation per tree) on July 29, PWP increased to similar levels in all trees but increase to maximum CS was delayed in HS trees, suggesting that prolonged moisture stress inhibited ability to recover.

INTRODUCTION

The ability of Prosopis glandulosa to resist drought and yet respond rapidly to short-term increases in soil moisture from rain showers gives it a competitive advantage over associated plant species. Under most conditions Prosopis will maintain rather than shed leaves during drought and carry on active photosynthesis and leaf transpiration during a time when associated herbaceous species are dormant. This mechanism to resist drought has been attributed to the ability of Prosopis root systems to access permanent or semi-permanent ground water supplies (Nilsen and others 1981). However, in regions such as the Rolling Plains of north central Texas where ground water is unavailable and plants must depend almost entirely on soil moisture in the surface horizons, Prosopis still maintain a full complement of leaves during all but the most severe droughts. Rolling Plains Prosopis invest more into lateral root growth than a tap root; and previous studies indicate that as dehydration of Prosopis increases dependence on lateral roots increases (Ansley and Jacoby 1986; Heitschmidt and others 198-). Prosopis in this region appear to be highly adapted toward maximizing use of moisture which becomes available in surface soil horizons following brief summer rain showers. It is not known how quickly Prosopis respond to a rainfall event and whether the condition of Prosopis, in terms of level of moisture stress, affects the plant's ability to respond.

We hypothesize that Prosopis in the Rolling Plains maximize use of water when it becomes available. The amount of water used is dependent on the amount available. Overall condition of the plant with respect to level of moisture stress may modify response to a moisture event in terms of plant water use activity. The objective of this study was to quantify rapidity, magnitude and duration of water use response of Prosopis to a moisture event when plants are in different initial levels of moisture stress.

MATERIALS AND METHODS

Site Description

Studies were conducted on the W.T. Waggoner Estate located 20 km south of Vernon in the northern Rolling Plains ecological area of Texas. Average annual precipitation is 65 cm, which occurs on the average in a spring/fall bimodal pattern. The clay loam range site supports primarily warm season grasses and forbs dominated by a moderate overstory (<30%) of Prosopis and lotebush, Ziziphus obtusifolia. Components of the understory include: Buchloe dactyloides, Bouteloua curtipendula, Digitaria californica, Aristida wrightii, Stipa leucotricha, Opuntia phaeacantha, O. leptocaulis, and Xanthocephalum dracunculoides.

Soils of the study area are Typic Paleustolls of the Deandale and Kamay series. Both soils have developed from redbeds or old alluvium and differences between the two are related to changes in topographic micro-relief. Deandale soils form where water tends to accumulate, whereas Kamay soils generally shed water to lower lying areas. Deandale soils tend to maintain a higher and more consistent moisture content throughout the soil profile than the Kamay soils, which become progressively drier with depth.

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R.J. Ansley is Postdoctoral Research Associate, P.W. Jacoby is Professor, and B.K. Lawrence is Technician, Texas A&M Agricultural Experiment Station, Vernon, TX.

Site Preparation

Twelve multistemmed Prosopis trees were selected as experimental units from the overstory component of the study site on the basis of uniformity in canopy shape and basal stem number. Plant shapes were selected to follow that of a parabolic frustrum to facilitate construction of subcanopy rain shelters. Trees were 3.0-3.5m in height with canopies of 4-6m diameter at the widest part.

All woody vegetation including nonexperimental Prosopis occurring within 10 m of each experimental tree was removed by chainsawing aerial portions and saturating remaining plant bases with diesel oil. Each experimental tree was containerized with a sheet metal and plastic vertical barrier to a depth of 2.5m. Containerization is described by Ansley and others (1988). Four 2m long x 5cm diameter aluminum access tubes were installed within each root container at 2m laterally from tree center for soil moisture measurements at 30cm vertical intervals using the neutron attenuation method (Greacen 1981).

Treatment Installation

Root containerization, irrigation, and rain shelters were used to generate surplus and reduced soil moisture levels available to Prosopis. Trees exposed to natural rainfall only were selected as the controls. Additional moisture was made available through trickle irrigation for the surplus treatment, and a reduced moisture level was created by installing a sub-canopy rainout shelter as the third treatment (Jacoby and others 1988). All twelve trees were equipped with a trickle irrigation system via underground polyvinyl chloride (PVC) tubing connected to a 23,000 L tanker and electric pump powered by a 4.5 kw generator to allow application of artificial moisture events. Water from a municipally approved drinking system was supplied via water truck to the tanker.

Stomatal Conductance and Water Potential

Stomatal conductance of adaxial leaflet surfaces was measured using two LICOR LI-1600 Porometers (LICOR Inc., Lincoln, NE). Porometer readings were taken on the northeast (NE) and southwest (SW) aspects of each of the twelve trees. It was determined in an earlier study that these aspects represented the least and most stressed, respectively, with respect to ambient exposure during a typical summer day. Two porometer readings were made per aspect during each sample period which occurred at 2, 5, 8 and 11 hours post sunrise (HPS). Duration of each sample period was about 1 hour. A sampling sequence was used that would prevent confounding of treatment effects with time should activity of the trees change during the sampling period. All readings were made on predominantly clear days. Only leaves on the perimeter of each canopy were sampled.

Leaf water potential was measured using a Scholander-type pressure bomb at predawn, and during porometer sampling periods. Two leaves were excised from the center of each canopy at 1.5-2m height and water potential determined in accordance with methods outlined by Turner (1981).

Photosynthetically active radiation (PAR, 400-700nm) was determined using a LICOR LI-190S-1 Quantum Sensor at each point where conductance was measured. Two PAR readings were taken, one with the sensor oriented vertically and a second with the sensor at leaf angle facing away from the basal center of the tree. PAR values reported in this study represent an average of the two readings.

Experimental Design

The conceptual strategy of this study was to manipulate Prosopis to different levels of moisture stress during the same growing season, then periodically expose all trees to the same moisture event and monitor responses (fig. 1). Because of a slight variation in soils across the study site, experimental trees were assigned treatments to conform to a randomized complete block design which included four blocks of three trees each. One block contained Deandale soils and the other three contained Kamay soils. Treatments within each block were designed to produce three levels of moisture stress as described earlier; thus, each of the three stress treatments was applied to four trees.

RESULTS AND DISCUSSION

Ambient Conditions

Air temperature, relative humidity (RH) and PAR values indicate that ambient conditions were similar on each of the sample days in 1986 (fig. 2). The most stressful part of the day occurred

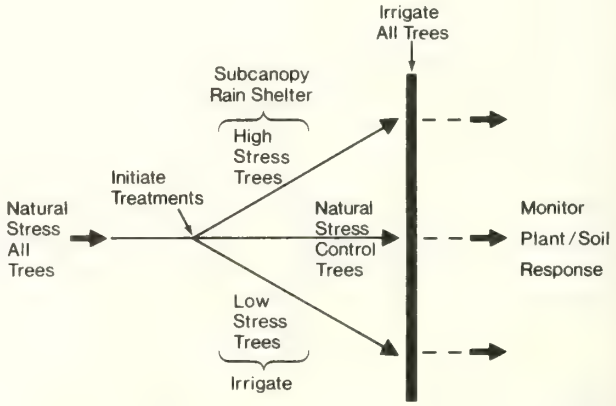

Figure 1--Schematic illustration outlining plan of the study to manipulate Prosopis to three levels of moisture stress, then treat all trees with an equivalent amount of irrigation, and monitor subsequent response by the trees.

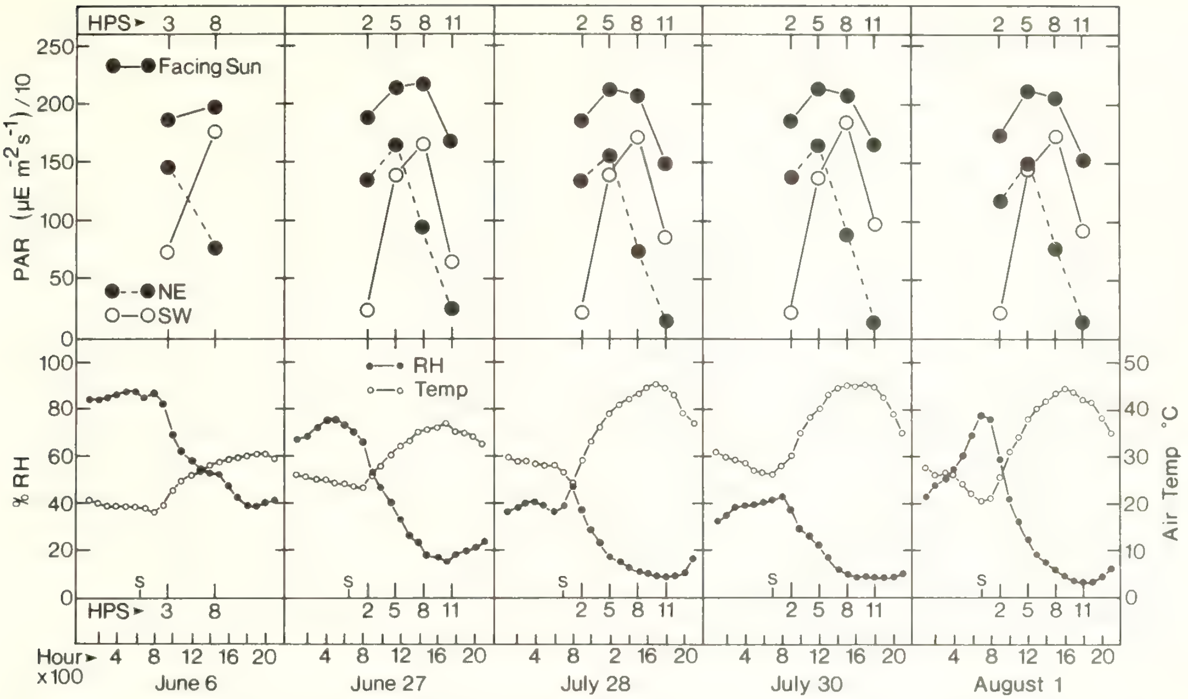

Figure 2--Photon flux density (400-700nm) facing the sun, and on NE and SW aspects of *Prosopis* canopies (top), and relative humidity and air temperature (bottom) during each of the sample days in 1986. HPS = Hours Post Sunrise, s = Sunrise.

in mid-afternoon from 8 to 11 HPS. Seasonal trends were typical in that at any HPS, RH and air temperature were greatest and least, respectively, in early June and least and greatest, respectively, in late July. Maximum PAR was similar for all sample days, indicating relatively clear and cloud free conditions. PAR changed with aspect during mornings and late afternoons, as was expected. PAR was greatest on the NE aspect early, then declined and became greater on the SW aspect by 8 HPS. Greater radiation and correspondingly greater leaf temperatures, coupled with extreme vapor pressure deficits (VPD), suggest that on a typical sunny day the most stressed portion of the canopy was on the SW aspect during afternoons. Conversely, leaves on the NE aspect would have most suitable conditions during mornings (i.e., high PAR and low VPD) to maximize photosynthesis and water use efficiency.

Moisture Treatments

All trees received frequent precipitation during April and May, 1986, prior to initiation of the moisture treatments (fig. 3). Rain shelters were imposed May 29, about two months following budbreak of *Prosopis*, which is winter deciduous. Control and Surplus moisture trees received precipitation during June and July. Surplus trees were irrigated additionally twice in June and twice in July. Our first trial to monitor response following watering of all trees on June 28 was terminated after June 30 because a 26mm rain occurred on July 1. Sufficient time was allowed to precondition the trees prior to a second trial which began July 29. A substantial storm which even breached the rain shelters to some degree precluded a third trial scheduled for early September (fig. 3). Prior to the July 29 trial, Surplus trees received 135mm more water than Control trees in four waterings, each equivalent to 30-40mm. Rain shelters shed 110mm precipitation during that time. All trees received 40mm irrigation on July 29.

Soil Moisture

Greatest flux in soil moisture occurred in the surface 30cm and declined progressively with depth (figs. 3 and 4). Soil moisture was maintained at levels higher than the control with supplementary irrigation at most depths, but surface evapotranspiration caused moisture to decline rapidly in the 30cm depth following each irrigation (fig. 3). Major differences in soil moisture between Control and Rainout plots were not found until the 60cm depth. Increases in moisture at 30cm caused by rain were probably not detected in Control plots because we were unable to measure moisture immediately following storms due to site inaccessibility. Conversely, effects of surplus irrigation were measured immediately following watering. This artifact in sampling appeared to be restricted to the 30cm depth.

Consistent differences between all three treatments were found at 60 and 90cm depths. Differences below 90cm were minimal, indicating neither surplus nor natural moisture infiltrated below this depth. A late summer storm yielded more than 250mm precipitation, and had a measurable effect to 150cm (fig. 4).

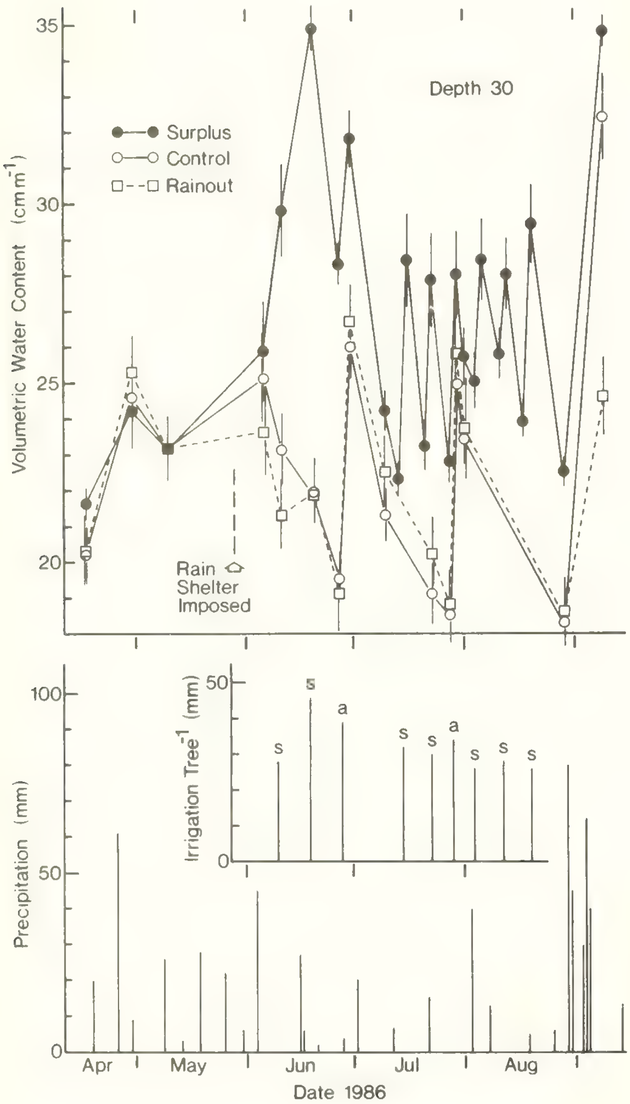

Figure 3--Soil water content at 30cm depth within root containers exposed to three moisture treatments (top), and time and amount of moisture received through natural precipitation and/or irrigation (bottom) during spring and summer 1986. Vertical dashed line indicates date rain shelters were imposed. Surplus = surplus irrigation plus natural precipitation. Control = precipitation only. Rainout = no watering except when all trees were watered June 28 and July 29. s = irrigation, surplus trees only; a = all trees irrigated. Vertical bars indicate ± 1 standard error of the mean.

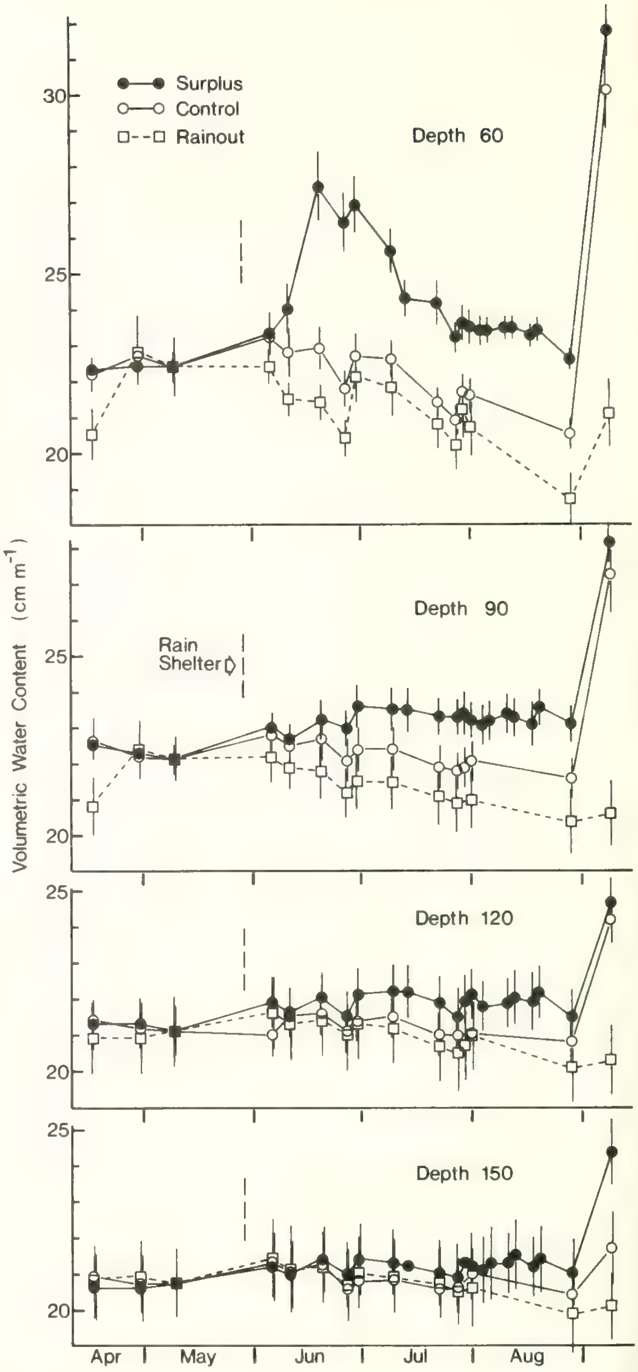

Figure 4--Soil water content at various depths within root containers of *Prosopis* trees conditioned to three different moisture treatments. Vertical dashed line indicates date in 1986 when rain shelters were imposed. Surplus = surplus irrigation plus natural precipitation. Control = precipitation only. Rainout = no watering except when all trees were watered June 28 and July 29. Vertical bars indicate ± 1 standard error of the mean.

Leaf Water Potential

Predawn leaf water potentials (WP) were significantly different between the three moisture treatments on June 27 and July 28 (fig. 5). Rain sheltered trees appeared to be under greatest stress according to predawn measurements on both dates. WP decreased in all treatments to -3 MPa by 2 HPS on both sample days and thereafter remained between -2 and -2.7 MPa (data not shown). Differences between treatments were not apparent during daylight hours on either day, indicating that for this species, predawn values offer the only valid assessment of moisture stress as it relates to leaf WP.

Effects of increasing stress from June 27 to July 28 were evident by a decline in predawn WP in all treatments to the point that Rainout trees had values below -2 MPa on July 28. Following irrigation of all trees on June 28 and July 29, differences between treatments were eliminated as WP increased to -0.9 and -1.2 MPa, respectively. Again, increasing seasonal stress caused WP to be lower following watering in July than in June. Rapid response of the trees following irrigation in the shallow root zone agrees with Sala and Lauenroth (1982) who noted the significance of small rainfall events on physiological condition of semi-arid species.

Stomatal Conductance

On both NE and SW aspects and across all treatments, stomatal conductance (CS) declined during each day, but the decline was sharper on the NE aspect following June 6 (fig. 6). These results were in response to increasing ambient temperature and decreasing RH (fig. 2).

Seasonally, while CS was generally greater across all HPS and both aspects, soil moisture was less at 30 and 60 cm depth in Surplus trees on June 6 than on June 27 (figs. 3, 4 and 6). This finding does not support the hypothesis that Prosopis uses water as it is available and suggests that ambient conditions may be the most important factor which regulates CS in early summer, as shown in figure 2. These results were not seen in the Control and Rainout trees during the same interval, as CS and soil moisture both declined. From June 27 to July 28, CS declined across all treatments and HPS, except at 11 HPS when CS was nearly zero on both dates (fig. 6). These results are consistent with corresponding changes in soil moisture, WP, air temperature and RH, and support findings by others (Thomas and Sosebee 1978).

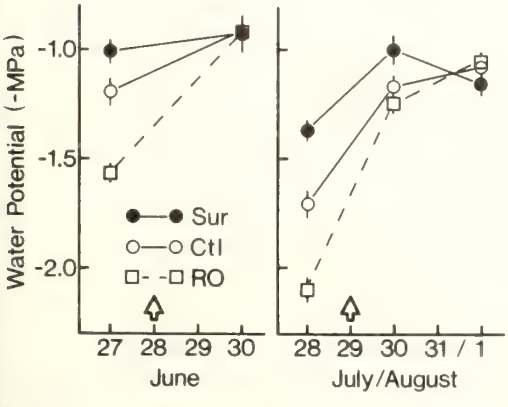

Figure 5--Predawn leaf water potentials of Prosopis exposed to three moisture treatments prior to and following irrigation of all trees (open arrows) on two dates in 1986. Sur = surplus + natural moisture, Ctl = control, RO = rainout treatment. Vertical bars indicate ± 1 standard error of the mean.

Clearest differences in CS as a result of moisture treatments were on the SW aspect on June 27 and July 28 (fig. 6). However, in spite of the fact that from May 29 to July 28 Surplus trees received 135mm more and Rainout trees received 110mm less moisture than Control trees (i.e., a moisture range of 245mm), there was surprisingly little difference in CS between treatments, especially on the NE aspect. Greater CS on the NE aspect in Surplus trees than in other treatments on June 27 and July 28 must be attributed to inherent variation among trees and not the surplus watering since these trends were apparent on June 6, prior to the first surplus irrigation. The fact that the SW aspect responded to soil moisture treatments rather than NE suggests that soil moisture content is fundamental to regulation of stomatal aperture only when ambient conditions are extreme. The tree will spend water for photosynthesis on the SW aspect in afternoons only when high available moisture conditions prevail.

Prosopis in this study appear to tolerate rather than avoid drought by maintaining high CS at low leaf WP at certain times, but not throughout the day. By adjusting magnitude of CS during the day, Prosopis can also be viewed as avoiding drought as outlined by Nilsen and others (1984), although this does not correspond to the classic definition of phreatophytic drought avoidance (Nilsen and others 1981). Nilsen's trees, described as phreatophytic, had access to free water at a shallow depth.

Stress History and Response to Moisture

Conductance in all trees increased across all HPS and both aspects within one day following irrigation on July 29 (fig. 7). The one day response was significantly greater than the three day response only at 8 (NE aspect) and 11 (SW aspect) HPS in Surplus trees. By contrast, greatest CS levels in the stressed trees, especially Rainout trees, did not occur until 3 days following irrigation, indicating that moisture stress retarded rapidity of response to a moisture event. The delayed response in stressed trees was more pronounced on the SW than NE aspect suggesting that recovery from stress was most difficult for leaves exposed to the most severe ambient conditions.

Across both aspects and most HPS, magnitude of response, in terms of increased CS, was greater in Surplus trees than other trees on both sample days following irrigation (Fig. 7). An August 3 rain halted further sampling; however, rapid stomatal closure on the SW aspect experienced by the Rainout, and to a lesser degree, the Control trees, but not the Surplus trees between 5 and 8 HPS on August 1 suggests that duration of response to the irrigation was related to stress history. These results agree with the review by Kaufmann (1981) which indicated that stress history has a significant effect on stomatal behavior and hydraulic flow of water, even though leaf water potential recovers rather quickly after rewatering.

SUMMARY AND CONCLUSIONS

One of the experimental goals of this study was to observe responses of large woody plants in situ to moisture events, yet employ methods to control moisture availability to each plant and thereby manipulate plants of the same species to different levels of physiological condition during the same growing season. Such a design would facilitate simulation of droughts as well as wet cycles during any season. We chose to begin our studies by modifying spring and summer conditions. While results reported in this paper represent only one year of data, we feel that the

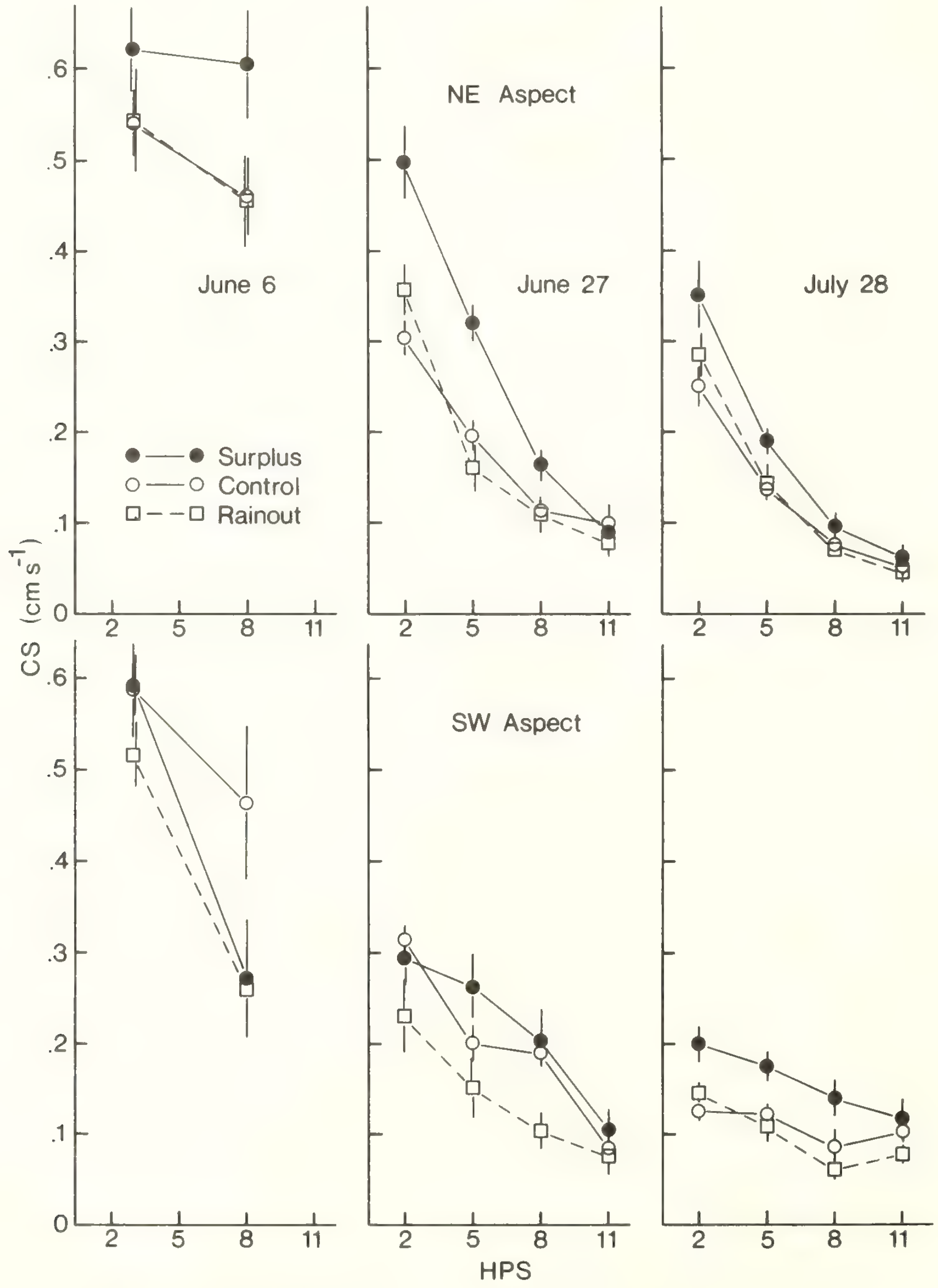

Figure 6--Diurnal stomatal conductance (CS) on northeast (NE) and southeast (SW) aspects of mesquite exposed to three moisture treatments on three dates in 1986. Vertical bars indicate ± 1 standard error of the mean.

treatment scheme we used created different moisture stress levels in Prosopis. Installment of the rain shelters occurred a month later than originally planned due to design problems, and we were unable to sufficiently precondition plants before late June.

The best overall indicator of moisture stress in Prosopis appeared to be predawn leaf water potential and not stomatal conductance, although differences in CS in response to stress treatments were measured. Stressed trees responded differently to moisture events than less stressed trees, suggesting that stress history influenced recovery from stress. Rapidity, magnitude and duration of response were slower, less, and shorter, respectively, in stressed than less stressed trees.

Water use by Prosopis (i.e., CS rate) was not always positively correlated with soil moisture content. As such, this study did not support a general hypothesis that Prosopis uses water as it is available. Ambient conditions coupled with level of plant stress influenced CS as much or more than soil moisture content during certain seasonal and/or diurnal periods.

Information from this study will be used to enhance current efforts by other research groups to model the water budget of Prosopis. As such, this study will augment long term efforts to increase rangeland watershed yield through proper brush control and management. This study will also aid in development of models concerning timing of herbicide application for Prosopis control (Dahl and Sosebee 1984). We feel there is a

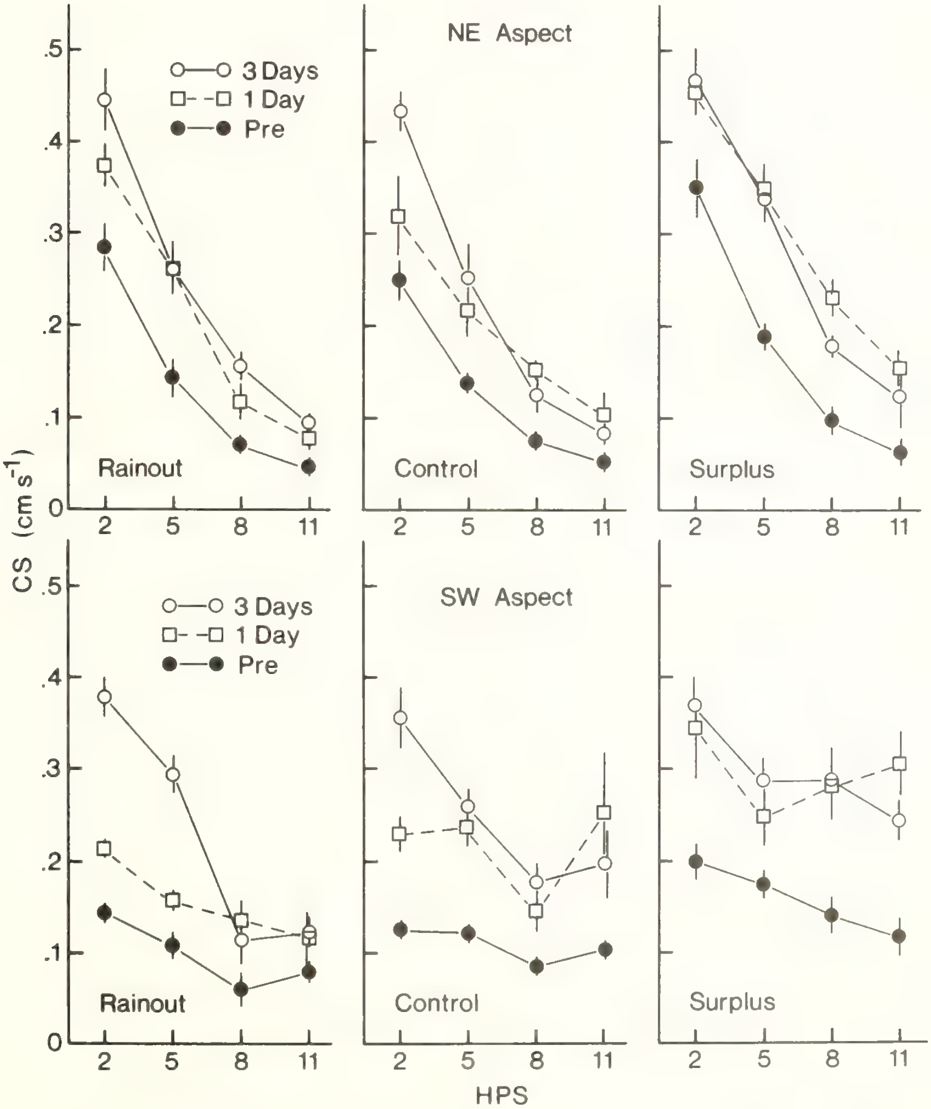

Figure 7--Diurnal stomatal conductance (CS) on the northeast (NE) and southwest (SW) aspects of mesquite trees pre-conditioned to three levels of moisture stress one day prior to (Pre) and one (1 Day) and three days (3 Days) following 40mm irrigation on July 29, 1986. Vertical bars indicate ± 1 standard error of the mean.

link between stomatal activity and efficacy of foliar applied herbicides. Information gained from this study can be incorporated into "decision aid" type models for determining date of herbicide application based on predicted conductance responses, given certain levels of plant stress and occurrence of precipitation events.

REFERENCES

Ansley, R.J.; Jacoby, P.W.; G.C. Cuomo. 1986. Lateral root restriction in honey mesquite: effects on plant and soil water relations. Abstr. In: Proceedings, Society for Range Management, 39th Annual Meeting, Orlando, FL.

Ansley, R.J.; Jacoby, P.W.; Lawrence, B.K. 1988. Root containerization for physiological studies of shrubs and trees on rangeland. Journal of Range Management. 41:90-91.

Dahl, B.E.; Sosebee, R.E. 1984. Timing - the key to herbicidal control of mesquite. Management Note 2, Department of Range and Wildlife Management, Texas Tech University, Lubbock.

Greacen, E.L.. 1981. Soil water assessment by the neutron method. CSIRO, East Melbourne, Victoria, Australia, 3002. 140 pp.

Heitschmidt, R.K.; Ansley, R.J.; Dowhower, S.L.; Jacoby, P.W.; Price, D.L. 198-. Some observations from the excavation of honey mesquite root systems. Submitted to Journal of Range Management.

Jacoby, P.W.; Ansley, R.J.; Lawrence, B.K. 1988. Design of rain shelters for studying water relations of rangeland shrubs. Journal of Range Management. 41:83-85.

Kaufmann, M.R. 1981. Water relations during drought. pp. 55-70 In: L.G. Paleg and D. Aspinall (eds.). The Physiology and Biochemistry of Drought Resistance in Plants. Academic Press, New York.

Nilsen, E.T.; Sharifi, M.R.; Rundel, P.W. 1981. Summer water relations of the desert phreatophyte Prosopis glandulosa in the Sonoran desert of southern California. Oecologia 50:271-276.

Nilsen, E.T.; Sharifi, M.R.; Rundel, P.W. 1984. Comparative water relations of phreatophytes in the Sonoran desert of California. Ecology 65:767-778.

Sala, O.E.; Lauenroth, W.K. 1982. Small rainfall events: an ecological role in semiarid regions. Oecologia 53:301-304.

Thomas, G.W.; Sosebee, R.E. 1978. Water relations of honey mesquite - a facultative phreatophyte. In: D.N. Hyder (ed.) Proceedings, First International Rangeland Congress, Denver, CO: 414-418

Turner, N.C. 1981. Techniques and experimental approaches for the measurement of plant water status. Plant and Soil 58:339-366.

A MODEL OF FREEZE TOLERANCE IN WINTERFAT GERMINANTS

D. Terrance Booth

ABSTRACT: Understanding freeze tolerance mechanisms in winterfat (Eurotia lanata) seedbeds could increase the successful culture of that plant on western rangelands. Under-snow germination and tolerance of nonwoody winterfat seedlings to subfreezing temperatures has been documented by several authors; however, seedling susceptibility to freezing has also been noted and is thought to contribute significantly to seedling mortality. This paper reviews plant freeze tolerance, describes exploratory work, and presents a hypothetical model of freeze tolerance in winterfat germinants.

INTRODUCTION

Freeze tolerance by young winterfat [Eurotia[1] lanata (Pursh) Moq.; Ceratoides lanata (Pursh) J.T. Howell] plants is a documented part of the plant's seedbed ecology (Wilson 1931; Hilton 1941; Woodmansee and Potter 1971). Like several other rangeland species, winterfat is a surface germinator whose diaspores are shed in fall or winter and germinate under cool, moist conditions. Depending on the weather, young plants may exist through weeks or months of freezing temperatures as imbibed seeds, as germinated seeds (germinants), or sometimes as nonwoody seedlings. This ecological strategy allows seedling establishment and root development before the heat and drought stress of summer. It also enables the plant to compete successfully with established warm season vegetation (Woodmansee and Potter 1971). Seedbed freeze tolerance is, therefore, a major factor in seedling establishment and in plant survival.

However, winterfat seedlings can be susceptible to frost, and freezing is suspected as a major decimator of early, cotyledon-stage plants (Stevens and others 1977; Hodgkinson 1975; Stevens and Monsen 1985). The reasons for tolerance and intolerance are not known, nor have any hypotheses been advanced. This paper will review some basic facts of plant freeze tolerance and will then consider the winterfat seedbed specifically. Exploratory work with winterfat germinants will be described and a hypothetical model of winterfat-germinant freeze tolerance will be presented.

THE PROCESSES AND PHYSIOLOGY OF FREEZE TOLERANCE

Acclimation

Acclimation and hardening are terms which describe the transition from the tender or freezing susceptible condition to the hardy, freeze tolerant condition in winter-hardy plants (Burke and others 1976). The transition occurs at the cellular level and affects membrane lipids (Yoshida 1982; Senser and Beck 1984; Lynch and Steponkus 1987), structural proteins of the membrane (Yoshida 1984), membrane enzymes (Ling-Cheng and others 1982; Hellergren and others 1983), and membrane associated cations, particularly Ca and Mg (Yoshida 1979a, 1979b, 1982; Pomeroy and Andrews 1985). These changes result in: membrane augmentation, an increased rate at which water can move through membranes (Scarth and Levitt 1937; Levitt 1978; Lyons and others 1979), cytoplasmic changes (Stout and others 1987), and changes to respiration machinery (Christiansen and St. John 1981; Cook and Cammack 1985).

Acclimation also is correlated with reduced plant-water content (Burke and others 1976). The degree of freeze tolerance is inversely related to tissue moisture in seeds (Junttila and Stushnoff 1977) and in herbaceous (Olien 1964; Metcalf and others 1970) and woody plants (Li and Wieser 1971; Levitt 1972; Olien and Smith 1981). Differences in the equilibrium moisture content appear to account for some of the differences in freeze tolerance among cereals and among seedlots of lettuce (Lactuca sativa L.) (Metcalf and others 1970; Keefe and Moore 1983).

Rates of Acclimation and Deacclimation

The time required to acclimate and to deacclimate varies by species and ranges from a few days to over 6 weeks (Olien and Smith 1981; Fennel and Li 1987). The greatest change in spinach (Spinacia oleracea L.) freeze tolerance occurred in the first 3 days of acclimation with little additional change after 14 days. Fully acclimated plants lost 3 to 5°C of freeze tolerance within 1 day. There was no further decline in tolerance after the third day of deacclimation. Wheat (Triticum aestivum L.)

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D. Terrance Booth is Range Scientist, USDA-Agricultural Research Service, Cheyenne, WY 82009.

[1] Proposals for conservation of this long-used generic name have been invited (Brummitt 1978).

requires 4 to 6 weeks to fully acclimate and becomes deacclimated in about the same time period (Fennel and Li 1987).

Freezing Point Depression and Supercooling

As hardy plants are cooled below 0°C, the cells and surrounding fluid remain unfrozen due to depression of the freezing point by the solutes present and to supercooling (Lyons and others 1979). The accumulation of solutes can give freezing protection to about -4°C (Levitt 1978). This protection is important to plants with limited hardiness, to acclimating plants, and it complements other freeze-tolerance mechanisms.

Supercooling, in which liquid water remains in the plant at temperatures below the freezing point, is an important means of freezing avoidance in some woody plants (Burke and others 1976) and in some imbibed seeds (Junttila and Stushnoff 1977; Keefe and Moore 1981, 1982). However, herbaceous plants seldom supercool more than a few degrees centigrade unless tissue moisture is very low (Burke and others 1976; Ashworth and others 1985). External ice can nucleate internal supercooled water through stomates and other openings (i.e. wounds or pores) having a diameter greater than 0.01 µm (Burke and others 1976; Keefe and Moore 1982; Ashworth and others 1985). Supercooled water in woody tissue and in seeds is apparently isolated from external ice.

Supercooling is also encouraged by interaction of plant cell walls and of associated xylan mucilages with water. Fixed patterns of hydrophilic groups in substances like cellulose tend to orient molecules of a covering water film into a matching pattern. This orientation affects the freezing point of water (Olien 1965; Dennis and others 1972). Freezing is also affected by long chain polymers of mucilages which inhibit ice formation by interfering with the diffusion of water molecules to ice crystal surfaces (Olien 1965; Olien and Smith 1981; Franks 1981). The effectiveness of mucilages as cryopotectants differ by species. The mucilages of rye (Secale cereale L.), for example, have been reported to be much more effective than those of barley (Hordeum vulgare L.) (Olien 1965).

Freeze-induced Dehydration

The freeze-dehydration process as described by Lyons and others (1979), begins at temperatures between -2 and -15 °C. The formation of ice crystals in the extracellular solution results in a disequilibrium between the chemical potential of the supercooled cytoplasm and the partially frozen extracellular fluid. Therefore moisture diffuses through the membrane to extracellular ice crystals. Cell dehydration is a function of membrane permeability and of the surface area of the plasma membrane relative to cell volume. Cell survival depends on intracellular water being removed at a rate consistent with the rate of temperature decrease. If the temperature decreases faster than the cell dehydrates, cytoplasmic supercooling is deepened and the probability of intracellular ice increases. Intracellular ice results in death of the cell.

Intracellular ice is the primary danger to the cell; secondary threats, which may also injure or kill the cell, are mechanical injury to the plasma membrane by extracellular ice and excessive dehydration (or excessively rapid rehydration; Steponkus and Wiest 1978). The effects of dehydration can be generally grouped into three categories of "solution effects" that include physical, chemical, and electrical consequences of reduced cell moisture (Steponkus 1984).

Cooling Rate

Both minimum temperatures and the cooling rate affect plant freeze tolerance. A cooling rate of 20°C/h was found to be too rapid for freeze dehydration to occur in imbibed lettuce seeds (Keefe and Moore 1981). The seeds were killed at -14 to -18°C, whereas those cooled at 1°C/h retained their viability after exposure to -25°C (the lowest temperature tested). The cooling rates and minimum temperatures a seed or germinant is exposed to in the natural environment are modified by the earth and by insulating materials such as snow and litter cover. It is unusual for soil surfaces in mid-latitude habitats to have cooling rates faster than 5°C/h (Lowe and others 1971; Keefe and Moore 1981).

FREEZE TOLERANCE IN WINTERFAT GERMINANTS

A germinant is the stage of plant development in which the radicle, but not the cotyledons, has emerged from the bracts and pericarp. Winterfat will germinate at temperatures as low as -1°C (Stevens and others 1977; Booth 1984) and Hilton (1941) and Woodmansee and Potter (1971) have described undersnow germination that produced vigorous seedlings which appeared unharmed by -10 to -13°C temperatures.

Acclimation

Fry (1969) found that winterfat seedlings acclimated best under short-day, cold temperature conditions and that 96% of acclimated 17-day-old seedlings survived -12°C. Survival was 32% or less for older seedlings and for those not acclimated. He concluded that younger seedlings were capable of a greater degree of freeze tolerance than older seedlings. Acclimated winterfat seedlings have a relatively high 87 to 88% moisture (Booth 1987).

Protective Function of Bracts

Dispersed winterfat diaspores in contact with the earth often have a cover of other diaspores (fig. 1), of litter, or of snow which may insulate the plant from temperature extremes and from rapid rates of temperature drop. In addition, the movement of Ca and Mg from diaspore bracts into the embryo during

Table 1--Pre- and postimbibition cation concentrations in winterfat bracts and seeds[1]

	Ca^{++}		Ma^{++}		K^{+}		Na^{+}	
	BRACTS	SEEDS	BRACTS	SEEDS	BRACTS	SEEDS	BRACTS	SEEDS
	µg/g							
Preimbibition	13667	992	4603	1717	13187	11005	493	240
Post imbibition	13593	1627	4269	2129	6295	11465	173	134
Amount change	-74	+635	-334	+412	-6892	+460	-315	-106
[2]Observed $F_{.05,1,4}$	0.01	12.06	6.25	7.71	7.71	0.29	3.85	5.62
[3]O.S.L.	NS	0.05	0.10	0.05	0.05	NS	NS	0.10

[1] Data are from Booth 1987. Values are mean of 3 replications.

[2] Testing the null hypothesis that postimbibition concentrations are not different from preimbibition concentrations.

[3] Observed significance level.

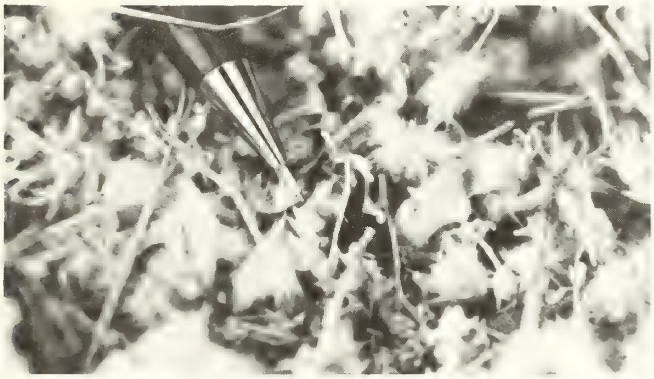

Figure 1--An aggregation of winterfat diaspores, litter and seedlings illustrating the protecting influence of covering material.

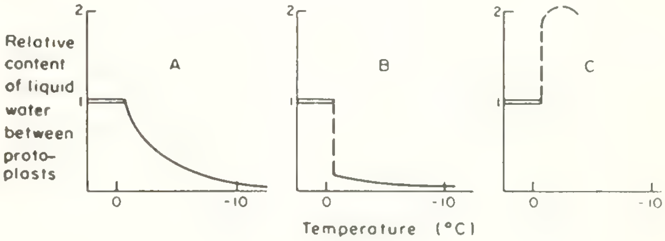

Figure 2--Three principal types of freezing patterns found in different tissues of the barley crown (Olien 1964); (A) Equilibrium freezing pattern, (B) Non-equilibrium freezing pattern, (C) Non-equilibrium freezing pattern typical of tender tissues.

imbibition (table 1) may increase freeze tolerance. Schmidt and others (1986) have found that salt treatment of hydroponically grown spinach hardened the leaves against mechanical damage of freezing. Salts from winterfat bracts may provide similar protection to winterfat germinants.

Supercooling and Freeze Dessication: A Test of Mechanisms

Introduction--Hilton (1941) reported vigorous growth from winterfat seedlings which were "frozen solid 16 hours of 24." However, he provided no evidence of ice crystals in plant tissues and his comment may have referred to the minimum temperature (-4°C) in his germinator. That temperature is within the range that plants tolerate cold by freezing avoidance; that is by freezing point depression and by supercooling.

To determine whether winterfat germinants supercool or freeze-dehydrate under nonlethal freezing, the conductivity methods of Olien (1961, 1964; Dennis and others 1972) were adapted to study freezing patterns in winterfat germinants. This entails measuring the conductivity of the plant's extracellular solution as the temperature is reduced. Olien (1964) has shown that as extracellular solutions freeze, the conductivity decreases; and, he has described equilibrium and nonequilibrium conductivity-freezing patterns in tolerant and intolerant plant tissue (fig. 2). An equilibrium freezing pattern is typical of acclimated tissue in which the extracellular moisture is closely associated with the cells, the equilibrium of water distribution shifts smoothly and the conductivity-freezing pattern is temperature controlled. The non-equilibrium patterns are not temperature controlled and are evidence of freezing injury to tissues. Figure 2-B shows sudden readjustment of extracellular liquid water. This type of freezing produces large, injury causing, ice crystals. Figure 2-C indicates rupture of protoplasts with freezing.

Methods--To study freezing patterns in winterfat germinants, diaspores were soaked for 2 days at 0 ± 2°C, allowed to germinate at temperatures between 0 and 5°C, then held at 0°C until used 7 to 14 days after being soaked. For each test the bracts and pericarp were removed from the cotyledons and the plant then bedded in dry graphite within the head-slots of two brass screws as shown in figure 3. Plants were sealed into the slot with a 1:10 wet paste of graphite and agar. When the paste dried, the screw heads (electrical contacts) were covered with silicone grease to prevent current being conducted in moisture that might occur on the outside of the plant. The test plant and contacts were then covered with a sheet of laboratory film and the apparatus connected to a YSI Model 32 conductivity meter with 0.4 mm diameter copper wire. The range of the conductivity meter was set on 2 µmohos and a strip chart recorder

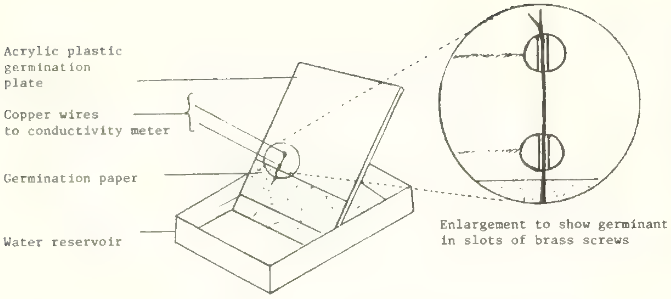
Acrylic plastic germination plate
Copper wires to conductivity meter
Germination paper
Water reservoir
Enlargement to show germinant in slots of brass screws

Figure 3--Illustration of experimental apparatus.

connected to the conductivity meter. The recorder span was 100 mV/FS and the chart rate was 0.25 cm/min. Plants were placed in the growth chamber and the system was allowed to equilibrate at 10°C for 1/2 h. The growth-chamber temperature was then dropped to -5°C at 7.5°C/h. A -5°C temperature was maintained for 1 h, after which the temperature was reduced to -20°C at an average rate of 5°C/h, reset to -5°C for 1 h then raised to 0°C. Minimum temperature was checked with a minimum/maximum mercury thermometer placed in the germinator adjacent to the test apparatus. The test plants were cultured at nonfreezing temperatures for several days after the test, to check viability.

Results and Discussion--During the tests conductance remained constant to -8°C to -11°C, then decreased as the temperature decreased. The conductance pattern (fig. 4) was similar to that described by Olien (1964) as an equilibrium freezing pattern, but occurred at lower temperatures than he has illustrated for barley crown tissues. The thawed germinants had no visible signs of damage though subsequent growth at warm temperatures was slow.

The tests indicate:
(1) that germinants can supercool to -8°C or lower. The capability to supercool 8 to 10°C may be a buffer against rapid cooling and would be a distinct advantage for high moisture plants germinating on the soil surface in harsh climates.
(2) that germinants can tolerate the formation of ice crystals in plant tissues and do freeze-dehydrate.
(3) that acclimated germinants can survive temperatures at least as low as -20°C.

There are some questions. These data contrast with observations that herbaceous plants seldom supercool more than a few degrees unless tissue moisture is very low (Burke and others 1976; Ashworth and others 1985). Keefe and Moore (1981) have shown that imbibed lettuce seeds will supercool to -16°C. However, this happens only if the endosperm, which acts as a nucleation barrier, is intact. There is no nucleation barrier in winterfat germinants. Further, the cellulose materials surrounding the test plants, or other conditions of test, may have allowed germinants to supercool to a degree that would not occur in the natural environment (Olien 1965). Finally, the conductivity data are only an indication of supercooling and not direct evidence.

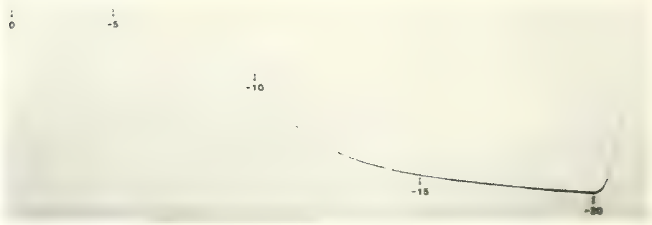

Figure 4--Strip-chart recorder output showing conductivity-freezing pattern of winterfat germinant. The recorder span was 100 mV/FS and the chart speed was 0.25 cm/m.

If germinants do naturally supercool, that capability must depend on the small size of the plant (Ashworth and others 1985), on interaction of water with plant cell walls and mucilages, and on lack of development of the vascular cylinder (Olien 1964; Dennis and others 1972). Vascular cylinder development increases the quantity of water in the conducting vessels and reduces intimate association of water molecules with living cells. Both factors increase the probability of ice nucleation.

Observations of fresh cross-sections of winterfat germinants and nonwoody seedlings under the microscope support the above observations. They also suggest an explanation for Fry's (1969) finding of decreased freeze tolerance with increased development of nonwoody seedlings. Cross-sections were obtained by placing germinants or young seedlings in water to which a few drops of safranin stain had been added. After 15-30 min. plants were sectioned at the point where the stem and root join, and the tissue examined and photographed under 100 and 250 magnification. Photomicrographs (fig. 5) of the same group of plants as germinants and 8 days later (4 days of which included 16 h/d at 20°C), as seedlings, show the older plants have root hairs, xylem vessels and large diameter cells not seen in the younger, less developed plants. The probable result of vessel development on freeze tolerance was discussed above. The larger cells may also reduce freeze tolerance. As a cell grows the surface area of the plasma membrane increases by the square, but the volume of the cell increases cubically. If the permeability of the plasma membrane remains constant, the larger cell has relatively less capacity to dehydrate and is more at risk as the temperature decreases.

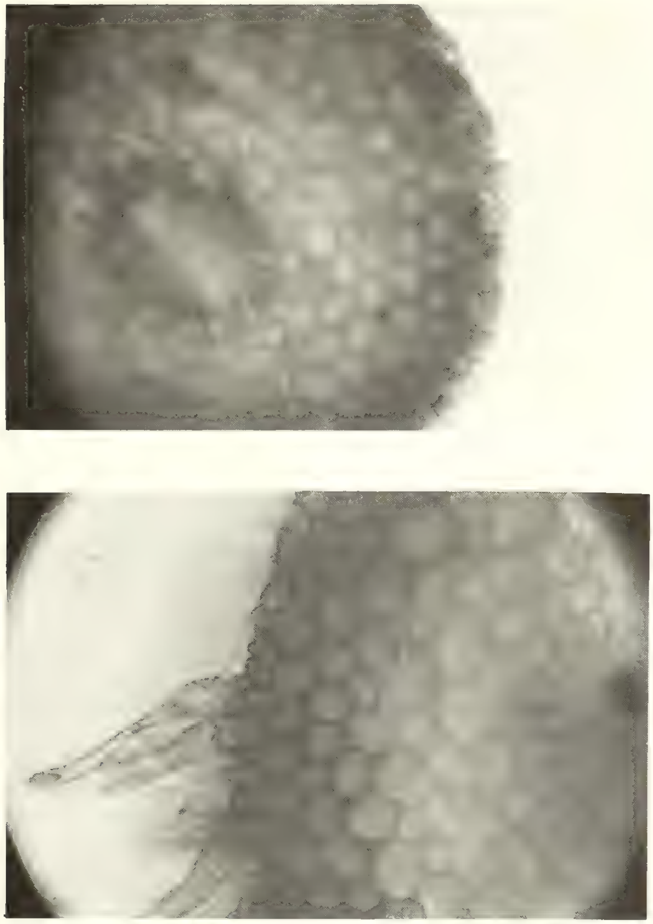

Figure 5--Fresh cross-sections of winterfat germinant (top) and seedling (bottom). x 100.

SUMMARY

The winterfat germinant's first defense against cold is the earth and the insulating influence of diaspore bracts, litter and snow. The second defense appears to be the capability to supercool at high moisture levels. That tentative capability, if it exists, is likely to be a function of plant size, immature cells and of an undeveloped vascular cylinder. Thirdly, winterfat germinants appear to undergo freeze dehydration, a process which may allow the plants to tolerate temperatures even lower than -20°C.

The literature reviewed and the exploratory work described have defined some important research questions relating to cold tolerance in nonwoody winterfat plants. As these questions are resolved and as our understanding of seedbed freeze tolerance is improved, our capability to successfully culture winterfat and other rangeland plants will be extended.

REFERENCES

Ashworth, Edward N.; Davis, Glen A.; Anderson, Jeffrey A. 1985. Factors affecting ice nucleation in plant tissues. Plant Physiology 79:1033-1037.

Booth, D. Terrance. 1984. Cold storage of germinating shrub seed prior to fluid drilling. Abstract of Papers. 37th annual meeting. Society of Range Management Abstract #088.

Booth, D. Terrance. 1987. Contributions to the reproductive autecology of winterfat [*Eurotia lanata* (Pursh) Moq.]. with notes on direct seeding methods. Ph.D. Dissertation. University of Wyoming, Laramie, WY.

Brummitt, R.K. (secretary). 1978. Proposal 413. 2232 *Eurotia* Adanson (1763) (Chenopodiaceae) vs. *Axyris* Linnaens (1753). Taxonomy 27:288.

Burke, M.J.; Gusta, L.V.; Quamme, H.A.; Weiser, C.J.; Li, P.H. 1976. Freezing and injury in plants. Annual Review of Plant Physiology 27:507-528.

Christiansen, M.N.; St. John, J.B. 1981. The nature of chilling injury and its resistance in plants. p. 2-13. *IN*: C.R. Olien and M.N. Smith (eds.) Analysis and Improvement of Plant Cold Hardiness. CRC Press, Inc., Boca Raton, FL.

Cook, Neil D.; Cammack, Richard. 1985. Effects of temperature on electron transport in *Arum maculatum* mitochondria. Plant Physiology 79:332-335.

Dennis, Frank G. Mr.; Lumis, Glen P.; Olien, C. Robert. 1972. Comparative freezing patterns in stems of cherry and azalea. Plant Physiology 50:527-530.

Fennel, Anne; Li, Paul H. 1987. Freezing tolerance and rapid cold acclimation of spinach. J. Amer. Soc. Hort. Sci. 112(2):306-309.

Franks, F. 1981. Biophysics and biochemistry of low temperatures and freezing. p. 3-19. *In*: Morris, G.J.; Clark, A. (eds). Effects of low temperature on biological membranes. Academic Press. London.

Fry, William C. 1969. The response of *Atriplex canescens* and *Eurotia lanata* to subfreezing temperatures. M.S. Thesis, University of New Mexico, Albuquerque.

Hellergren, J.; Widell, S.; Lundborg, T.; and Kylin, A. 1983. Frost-hardiness development in *Pinus sylvestris*: the involvement of a K^+-stimulated Mg^{++}-dependent ATPase from purified plasma membranes of pine. Physiologia Plantarum. 58:7-12.

Hilton, J.W. 1941. Effects of certain micro-ecological factors on the germinability and early development of *Eurotia lanata*. Northwest Science 15:86-92.

Hodgkinson, Harmon S. 1975. Evaluation of winterfat (*Eurotia lanata*) in Washington. Journal of Range Management 28:138-141.

Jian, Ling-Cheng; Sun, Long-Hua; Dong, He-Zhu. 1982. Adaptive changes in ATPase activity in the cells of winter wheat seedlings during cold acclimation. Plant Physiology 70:0127-0131.

Junttila, Olavi; Stushnoff, Cecil. 1977. Freezing avoidance by deep supercooling in hydrated lettuce seeds. Nature 269:325-327.

Keefe, P.D.; Moore, K.G. 1981. Freeze desiccation: a second mechanism for the survival of hydrated lettuce (*Lactuca sativa* L.) seed at sub-zero temperatures. Annals of Botany 47:635-645.

Keefe, P.D.; Moore, K.G. 1982. Frost damage during stratification: Mechanism and protection in *Pinus sylvestris* seed. Seed Science and Technology 10:485-494.

Keefe, P.D.; Moore, K.G. 1983. Freezing tolerance in hydrated *Lactuca sativia* (L) seed: a model to explain observed variation between seed lots. Annals of Botany 51:373-383.

Levitt, J. 1972. Response of plants to environmental stresses. Academic Press. New York.

Levitt, J. 1978. An overview of freezing injury and survival, and its interrelationships to other stresses. p. 3-15. *In*: P.H. Li and A. Sakai (eds.) Plant Cold Hardiness and Freezing Stress. Academic Press, New York.

Li, P.H.; Weiser, C.J. 1971. Increasing cold resistance of stem sections of *Cornus stolonifera* by artificial dehydration. Cryobiology 8:108-111.

Lowe, C.H.; Lardner, P.J.; Halpern, E.A. 1971. Supercooling in reptiles and other vertebrates. Comparative Biochemistry and Physiology 39A:125-135.

Lynch, Daniel L.; Steponkus, Peter L. 1987. Plasma membrane lipid alterations associated with cold acclimation of winter rye seedlings (*Secale cereale* L. cv Puma). Plant Physiology 83:761-767.

Lyons, J.M.; Raison, J.K.; Steponkus, Peter L. 1979. The plant membrane in response to low temperature; an overview. p. 1-24. *In*: J.M. Lyons and others (eds.) Low temperature stress in crop plants-the role of the membrane. Academic press, New York.

Metcalf, E.L.; Cress, C.E.; Olein, C.R.; Everson, E.H. 1970. Relationship between crown moisture content and killing temperature for three wheat and three barley cultivars. Crop Science 10:362-365.

Olien, Charles R. 1961. A method of studying stresses occurring in plant tissue during freezing. Crop Science 1:26-28.

Olien, Charles R. 1964. Freezing processes in the crown of 'Hudson' barley, *Hordeum vulgare* (L. emend. Lam.) Hudson. Crop Science 4:91-95.

Olien, Charles R. 1965. Interference of cereal polymers and related compounds with freezing. Cryobiology 2:47-54.

Olien, C.R. and Smith, Myrtle N. 1981. Protective systems that have evolved in plants p. 61-87. *In*: C.R. Olien and Myrtle N. Smith. (eds.) Analysis and improvement of plant cold hardiness. CRC Press, Inc. Boca Raton, Florida.

Pomeroy, M. Keith; Andrews, Chris J. 1985. Effect of low temperature and calcium on survival and membrane properties of isolated winter wheat cells. Plant Physiology 78:484-468.

Scarth, G.W., and J. Levitt. 1937. The frost-hardening mechanisms of plant cells. Plant Physiology 12:51-78.

Schmidt, J.E.; Schmidt, J.M.; Kaiser, W.M.; Hincha, D.K. 1986. Salt treatment induces frost hardiness in leaves and isolated thylakoids from spinach. Planta 168:50-55.

Senser, Margot; Beck, Erwin. 1984. Correlation of chloroplast ultrastructure and membrane lipid composition to the different degrees of frost resistance achieved in leaves of spinach, ivy, and spruce. Journal of Plant Physiology 117:41-55.

Steponkus, Peter L. 1984. Role of the plasma membrane in freezing injury and cold acclimation. Annual Review of Plant Physiology Vol. 35:543-584.

Steponkus, P.L.: Wiest, S.C. 1978. Plasma membrane alterations following cold acclimation and freezing. p. 75-91. *In*: P.J. Li and A. Sakai (eds.) Plant Cold Hardiness and Freezing Stress. Academic Press, New York.

Stevens, R.; Giunta, B.C.; Jorgensen, K.R.; Plummer, A.P. 1977. Winterfat (*Ceratoides lanata*). Utah State Div. of Wildlife Res. Pub. No. 77-2.

Stevens, R.; Monsen, S.B. 1985. Recent Plant Releases For Western Wildlands. p. 34-36. *In*: 39th Annual Reports-Vegetative Rehabilitation and Equipment Workshop. U.S. Forest Service Equipment Development Center, Missoula, Montana.

Stout, Darryl G.; Hall, John W.; McLaughlin, Neil B. 1987. In vivo plant impedance measurements and characterization of membrane electrical properties: the influence of cold acclimation. Cryobiology 24:148-162.

Wilson, C.P. 1931. The artificial reseeding of New Mexico ranges. New Mexico Agricultural Experiment Station Bulletin 189.

Woodmansee, Robert G.; Potter; Loren D. 1971. Natural reproduction of winterfat (*Eurotia lanata*) in New Mexico. Journal of Range Management 24:24-30.

Yoshida, S. 1979a. Freezing injury and phospholipid degradation in vivo in woody plant cells. II. Plant Physiology 64:247-251.

Yoshida, S. 1979b. Freezing injury and phospholipid degradation in vivo in woody plant cells. III. Plant Physiology 64:252-256.

Yoshida, S. 1982. Fluorescence polarization studies on plasma membrane isolated from mulberry bark tissues. p. 273-284. *IN*: P.H. Li and A. Sakai (eds.) Plant Cold Hardiness and Freezing Stress. Academic Press, New York.

Yoshida, S. 1984. Studies on freezing injury of plant cells. I. Relation between thermotropic properties of isolated plasma membrane vesicles and freezing injury. Plant Physiology 75:38-42.

WATER RELATIONS, ABOVEGROUND GROWTH, AND PHENOLOGY OF *ARTEMISIA TRIDENTATA* SPP. *VASEYANA*

IN RELATION TO DISPERSION PATTERN

Alan T. Carpenter and Neil E. West

ABSTRACT: Water relations, growth, and phenology of *Artemisia tridentata* ssp. *vaseyana* (mountain big sagebrush) were investigated in a field experiment in southwestern Wyoming. *Artemisia* transplants were grown in plots where the individuals were either regularly dispersed or clumped. Overall, plants in the regularly dispersed treatments appeared to have a growth advantage compared to clumped plants. This probably reflected greater use of soil water by the regularly dispersed plants and more deposition of blowing snow among the regularly dispersed shrubs.

INTRODUCTION

Shrubs in arid environments commonly grow in clumps (MacMahon and Schimpf 1981; West 1987). This could arise from limited seed dispersal ability, causing recruitment to be concentrated near the maternal parent plants (Friedman and Orshan 1975). Alternatively, the clumps could develop in microsites where resources such as water and nutrients are concentrated (Waisel 1971; Barbour and others 1977). It is also possible that clumps of shrubs could improve their local environmental conditions by trapping blowing snow and airborne particulates, and by serving as foci for animal activity (West 1987).

If clumps of shrubs develop largely from limited seed dispersal, the clumps should be transient, with dispersion changing to a more random or even regular pattern over time. Closely spaced plants would succumb from the effects of competition more rapidly than shrubs spaced farther apart. Efforts to detect changes in pattern with increasing shrub size or age or on low precipitation sites have produced mixed results (for example, Beals 1968; Anderson and others 1969; Woodel and others 1969; Barbour and Diaz 1973; Malik and others 1976; Williams and others 1978; Phillips and MacMahon 1981; West and Goodall 1986). Perhaps, this is not surprising in view of the usual lack of control over local variations in soil moisture (Greig-Smith and Chadwick 1965).

The results of manipulative experiments indicate that plants in hot deserts can compete with their neighbors for water. Fonteyn and Mahall (1978, 1981) found in their removal experiments in the Mojave Desert of California, that plants that had their neighbors removed had more positive xylem water potentials than control plants. Robberecht and others (1983), also using removal experiments in the Mojave Desert, found that *Hilaria rigida* individuals with their nonspecific neighbors removed had more positive leaf water potentials plus greater leaf conductances, and greater above- and belowground biomass production than control individuals. Ehleringer (1984) removed the neighbors from *Encelia farinosa* individuals in the Sonoran Desert of Arizona and found that these *Encelia* plants responded with improved water relations, growth, and reproduction relative to control individuals.

It is unclear if the above results apply to cool semi-deserts, such as the Great Basin. Here, annual precipitation is typically greater, and potential evapotranspiration is lower than in the Mojave or Sonoran Deserts. Most precipitation in the Great Basin falls as snow, which is considerably redistributed by prevailing winds and, at least in some locations, tends to accumulate around shrubs. In this region, clusters of shrubs may result from a combination of topographic position and moisture accumulation with shrubs themselves causing substantial amounts of snow to accumulate (Allen and others 1987).

METHODS

Study Site and Experimental Design

The study site was located at the Pittsburgh & Midway Coal Mining Company's coal strip mine near Kemmerer in southwestern Wyoming. The site was stripmined in the late 1970's, later backfilled and regraded. The original topsoil, which had been stockpiled nearby, was reapplied to a depth of 10-20 cm in August 1981. It is likely that disturbance of the site during topsoil removal, stockpiling, and reapplication greatly reduced spatial variation in soil properties such as nutrient content and texture. Islands of fertility (Garcia-Moya and McKell 1970; Charley and West 1975) which may have existed on the site prior to mining, were eliminated; thus, the experimental shrubs initially experienced a relatively uniform soil environment.

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Alan T. Carpenter is Research Associate, Department of Range Science, Colorado State University, Fort Collins, CO; Neil E. West is Professor, Department of Range Science, Utah State University, Logan, UT.

The site elevation was 2,210 m and the mean annual precipitation from 1951 through 1980 at the town of Kemmerer, about 15 km east of the study site, was about 230 mm, about half of which fell as snow (National Oceanic and Atmospheric Administration 1982). The experimental plots were located on a gentle east-facing slope.

The local vegetation is included in the western Intermountain sagebrush steppe type (West 1983) with woody Artemisia species as the dominant plants. Winters are long and severe. The growing season for A. tridentata ssp. vaseyana in this locale lasts from late May to mid-August.

Artemisia tridentata ssp. vaseyana (mountain big sagebrush) was selected as the experimental shrub. It is abundant locally and dominates 10 million hectares of U.S. rangeland (Beetle 1960). On the basis of biweekly observations of snow accumulation during the winter of 1981-82, shrub clumps were seen to collect substantial amounts of snow.

One-year-old mountain big sagebrush transplants were planted in May, 1982, either individually (clumps of 1) or in clumps of four. There were three blocks each of the clump-1 and clump-4 plots. Within each clump-1 plot, 49 individuals were situated in a grid pattern with an interplant distance of 1.3 m along the main grid axis. Within each clump-4 plot, the distance between plants within a clump was 0.4 m, and the clumps were 2.6 m apart center to center (fig. 1). The overall density in the clump-1 and clump-4 plots was the same, namely 0.6 plants m^{-2}.

Because of their great size range, seedlings were separated into groups of large, medium, and small plants prior to transplanting. Plant material for each treatment was randomly drawn from each of the three groups for the three blocks, respectively. Thus, the experiment was blocked by initial plant size. Hereafter, small-, medium-, and large-plant blocks refer to the blocks consisting initially of the small, medium, and large plants, respectively. The plots were randomly assigned to positions in a long, rectangular strip of land. The randomization resulted in complete segregation of the treatment blocks (fig. 1). Hurlbert (1984) argued that such designs lack interspersion and should not be subjected to inferential statistical analysis. We have followed his suggestion.

Data were collected on the interior plants and the average computed for each block. All of the plots were weeded regularly to eliminate potentially confounding effects of differential weed density. During 1983 and 1984, meterological data were collected at a weather station located about 300 m from the study site.

Soil and Plant Water Potential

During the summers of 1983 and 1984, soil water potential at 20- and 50-cm depths under four plants in each plot was determined using soil thermocouple psychrometers installed in 1982.

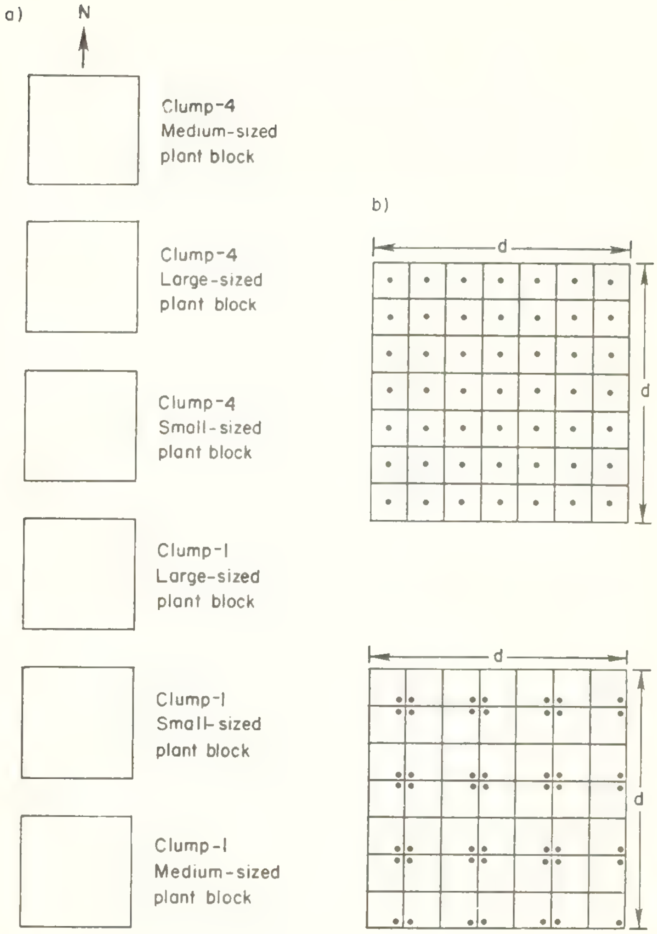

Figure 1.-- Schematic for clump-1 and clump-4 plots. (a) Plot layout in the field showing lack of interspersion; (b) dispersion patterns used in clump-1 (top) and clump-4 (bottom) plots. "Cell" dimensions are 1.3 by 1.3 m. Plant spacing within clumps of 4 = 0.4 m. Each "." denotes one shrub.

Also, two pairs of psychrometers were installed at the same soil depths between adjacent plants (clump-1) or between adjacent clumps (clump-4) in each plot. Measurements were made at dawn. Water potentials were calculated using a computer program that compensates for variable psychrometer correction coefficients, zero offsets, and soil temperatures (Brown and Bartos 1982).

In 1984, predawn and midday leaf water potentials were measured using leaf thermocouple psychrometers. From four to six ephemeral leaves were plucked from the top of each sample plant canopy (n=6 per plot) then quickly sealed inside a leaf psychrometer chamber. After a 2-hr equilibration period in an insulated water bath, the microvolt output of each psychrometer was recorded. The psychrometers were then frozen in liquid nitrogen, thawed in a bucket of water, and placed in the water bath for another 2 hr. The microvolt output of each psychrometer was again recorded. Total water potential and osmotic potential were calculated using data from fresh and thawed leaf samples, respectively. The osmotic potentials were corrected for dilution of the symplastic water by apoplastic water by dividing each osmotic potential by 0.90, the average symplastic water fraction, which was obtained from pressure-volume curves. The difference between a sample's total water potential and corrected osmotic potential was considered to be a measure of leaf turgor potential.

Aboveground Phytomass

About a month after outplanting, the total aboveground mass of each of the big sagebrush transplants was estimated using the reference unit method (Andrew and others 1979, 1981; Carpenter and West 1987). This procedure was repeated at the end of the 1982, 1983, and 1984 growing seasons. The phytomass estimates were transformed to natural logarithms and the average relative growth rates for the three growing seasons were calculated (Hunt 1978).

The use of average relative growth rate permits valid comparisons even though the initial mean phytomass values were unequal, thus eliminating any possible bias created by the existence of the larger plants in the large plant block of the clump-1 treatment. During this first year the initial phytomass estimates were made on June 17, therefore, the phytomass estimates for 1982 reflect growth over only part of the growing season. The average relative growth rates for the first year are not comparable to the average relative growth rates for the subsequent two seasons.

Twig Phenology

During the 1983 and 1984 growing seasons, twig phenologies were sampled on 16 plants in each of the experimental plots. Three twigs were selected in a stratified random manner, one twig located on the east, west, and south side of each plant. The selected twigs were tagged with 2-cm length of different colored insulated wire so each twig could be followed over the growing season. At approximately weekly intervals, twig phenology was assessed on the same twigs using a scale modified from DePuit and Caldwell (1973).

RESULTS

Soil and Plant Water Potential

Differences between the clump-1 and clump-4 soil water potential means under plants both at the 20- and 50-cm depths were generally small during 1983 (fig. 2b). There was no clear tendency for the clump-1 means to be more negative or positive than the clump-4 means. On most sampling dates, the soil water potential means at 50 cm were greater than those at 20 cm, regardless of clump type. Mean values of soil water potential under plants never dropped below -1.22 MPa, and for much of the season were greater than -1.0 MPa.

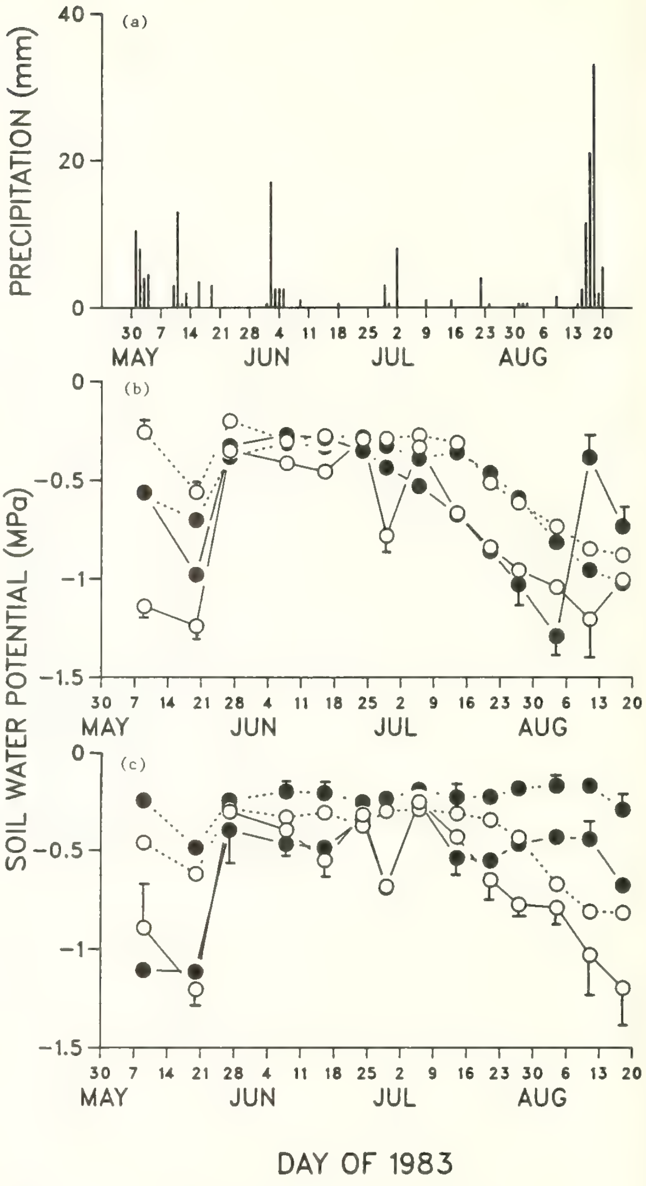

Figure 2.-- Precipitation and soil water potential in clump-1 and clump-4 plots during May-August 1983. (a) Precipitation at study site; soil water potential, (b) under plants, and (c) in interspaces between plants. Open symbols denote clump-1 means, and closed symbols denote clump-4 means. Solid lines connect 20-cm-depth means, and dotted lines connect 50-cm depth means. Vertical bars equal 1 S.E.M.; n=3.

Soil water potentials in the interspaces of the clump-1 and clump-4 plots during 1983 were very similar to those under plants at both the 20- and 50-cm soil depths until early July (fig. 2c). Thereafter, the soil water potentials in the clump-4 plots decreased only slightly while those in the clump-1 plots decreased more precipitously.

During 1984, soil water potential under plants in the clump-1 plots generally equaled or exceeded that in the clump-4 plots at 20 cm while the reverse was true at 50 cm (fig. 3b). Soil water potential at 20 cm was less than that at 50 cm in both the clump-1 and clump-4 plots.

Soil water potential in the interspaces between plants in the clump-1 plots was nearly always lower than in the clump-4 plots (fig. 3c). During July and August, the difference between clump-1 and clump-4 soil water potential increased at both soil depths.

Both predawn and midday leaf water potentials during 1984 in clump-1 plots were slightly higher than in clump-4 plots (fig. 4a). Leaf water potential usually dropped from predawn to midday for both clump types, increasingly so until late July. Clump-1 plots did not exhibit consistently lower or higher daily change in leaf water potential than clump-4 plots.

Leaf osmotic potentials of clump-1 plants were consistently greater than those of clump-4 plants after June 11 (fig. 4b). There was no consistent difference in daily decline in osmotic potential or in predawn or midday turgor potential between the clump-1 and clump-4 plots. There was no evident trend for daily decline in leaf turgidity to increase seasonally (fig. 4c).

Aboveground Phytomass

At the end of the 1982, 1983, and 1984 growing seasons, the mean phytomass for the clump-1 plots consistently exceeded the mean for the clump-4 plots (table 1). However, this occurred because the initial mean for the clump-1, large-plant block was 50 percent larger than the corresponding initial clump-4 plot mean.

Table 1.--Initial and end-of-season aboveground phytomass of individual plants in clump-1, clump-4 plots for 1982-84. Means (g) ± 1 S.E.M., n=3

	Initial	End-of-Season		
	1982	1982	1983	1984
Clump-1	2 ± 1	7 ± 3	100 ± 30	230 ± 80
Clump-4	1 ± 0	5 ± 1	80 ± 4	180 ± 20

The average relative growth rates were very similar for the clump-1 and clump-4 plots for all 3 years (table 2). Relative growth rate declined markedly from the 1983 to 1984 growing seasons.

The clump types were not very different in their phenological progression from dormant buds to rapidly elongating vegetative twigs to initiation of floral buds (table 3). As the 1983 season

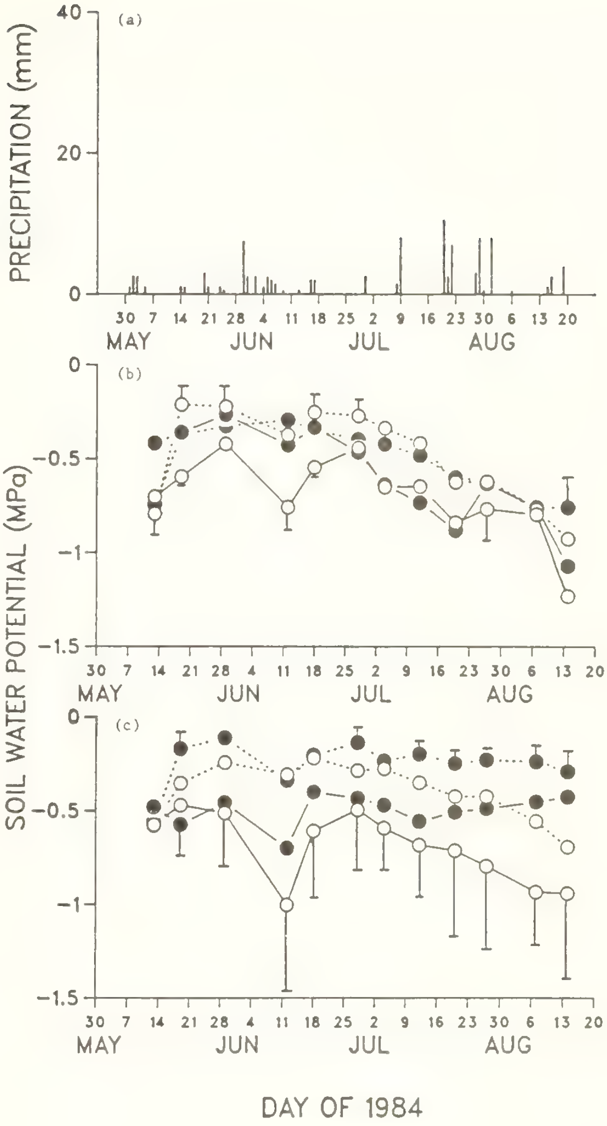

Figure 3--Precipitation and soil water potential in clump-1 and clump-4 plots during May-August 1984. (a) Precipitation and study site; soil water potential, (b) under plants and, (c) in interspaces between plants. Open symbols denote clump-1 means, and closed symbols denote clump-4 means. Solid lines connect 20-cm-depth means, and dotted lines connect 50-cm-depth means. Vertical bars equal 1 S.E.M., n=3.

Table 2--Average relative growth rate of individual plants in clump-1 and clump-4 plots for 1982-84. Means (year^{-1}) ± 1 S.E.M., n=3. For additional details regarding units, see text

	Beginning of 1982 growing season--end of 1982 grow season	End of 1982 growing season--end of 1983 grow season	End of 1983 growing season--end end of 1984 grow season
Clump-1	1 ± 0	3 ± 0	1 ± 0
Clump-4	1 ± 0	3 ± 0	1 ± 0

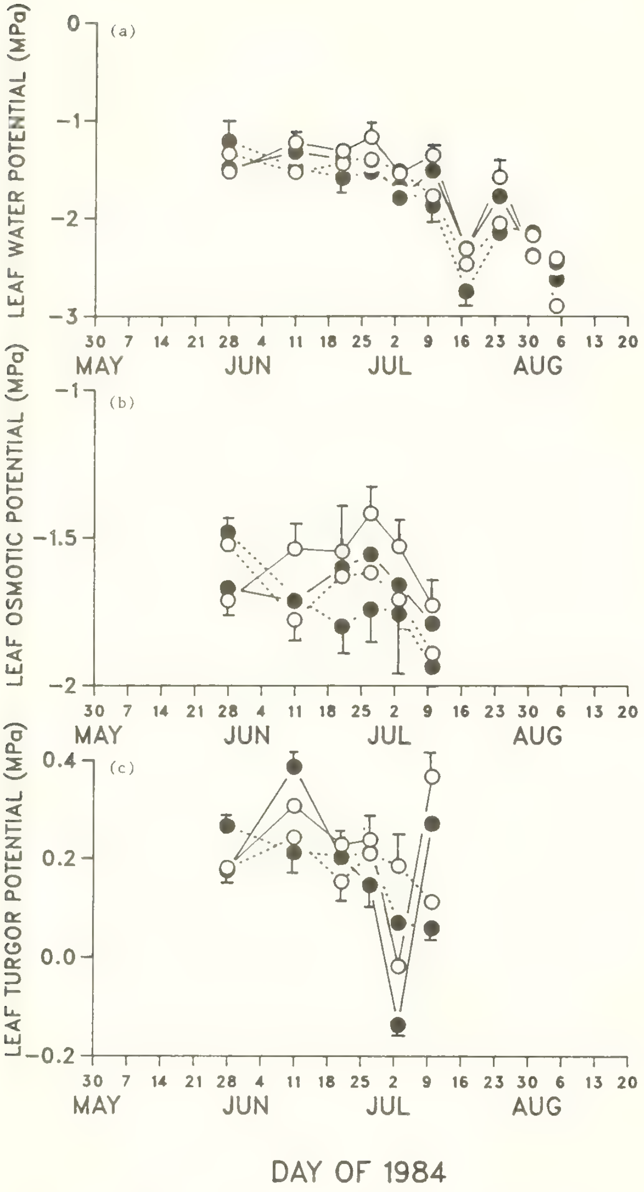

Figure 4--Water potential components in clump-1 and clump-4 plots during May-August 1984. (a) Total, (b) osmotic and, (c) turgor potential. Open symbols denote clump-1 means, and closed symbols denote clump-4 means. Solid lines connect predawn means, and dotted lines connect midday means. Vertical bars equal 1 S.E.M., n=3.

progressed, the proportions of twigs in the first three categories were fairly similar for the clump-1 and clump-4 plots. However, the clump-1 plots consistently had about twice as many twigs with floral buds developing as did the clump-4 plots. In 1984, the proportions of twigs in the various phenological stages were similar on each sampling date (data not shown).

DISCUSSION

There were few differences in soil water potential directly under the shrubs attributable to clump type. Soil water potential appeared to be much more affected by depth of measurement and the presence or absence of recent precipitation. However, differences in soil water potential between plants in the clump-1 and clump-4 plots did develop in the latter half of the 1983 and 1984 growing seasons. Soil water potentials at 20 and 50 cm were similar under plants and in the interspaces between plants in the clump-1 plots (figs. 2 and 3). This contrasts with the clump-4 plots where soil water potentials at both depths were higher in the shrub interspaces. Clump-4 plant roots may have extracted less soil water than the clump-1 plants. Thus, considerable soil moisture between the clumps of four plants may have gone unutilized by the shrubs both years. This is consistent with our observations that recruitment and initial growth of weeds was greater in the clump-4 plots compared to the clump-1 plots.

During the latter half of the 1984 growing season, differences in soil water potential among the large-, medium-, and small-plant blocks developed. At 50 cm, both under plants and in the interspaces between plants, the large-plant blocks had the lowest soil water potential while the small-plant blocks had the highest. In addition, differences between treatments were greater for the large-plant blocks than for the other blocks. Thus, the treatments may have had an influence only with the large-plant blocks. The shrubs may have had to attain some minimum size before dispersion pattern had any effect on soil water potential.

Mountain big sagebrush roots within the perimeter of the clumps of four plants may have overlapped greatly. However, the plants did not fully compensate by extending root growth laterally into soil with high water potential. Rodriguez (1985) found that mountain big sagebrush individuals planted in the vicinity of our plots exhibited little lateral root growth, with most roots located within 30 cm of the plant center. In September 1984, we excavated two isolated sagebrush shrubs that had been planted at the same time as the experimental plots. Soil was removed in 20-cm layers to a depth of 60 cm and outward to 1 m in one quadrant adjacent to each shrub. Visible roots were concentrated under each canopy, although an occasional root extended farther from the shrubs. Vertically, roots appeared to be most abundant from 0-30 cm in the soil. Tabler (1964) and Sturges (1977) found that mountain big sagebrush roots were concentrated close to the plants, although the maximum lateral spread was about 1.5 m. Root competition for soil water within the clumps may have reduced or eliminated any benefit those plants might have derived from snow trapping.

Table 3.--Phenological stage of tagged twigs in clump-1 and clump-4 plots in 1983. Percentages of twigs in each phenological stage. Phenological stage 2 = overwintering buds not elongating; 3 = twigs rapidly elongating in vegetative phase; 4 = floral buds developing

Phenol.	6 June		14 June		23 June		29 June	
stage	Clump-1	Clump-4	Clump-1	Clump-4	Clump-1	Clump-4	Clump-1	Clump-4
Dead	0	0	0	1	0	1	0	1
2	34	41	25	26	22	24	19	23
3	66	59	75	73	78	75	81	76
4	0	0	0	0	0	0	0	0
	6 July		13 July		21 July		27 July	
Dead	0	1	3	1	4	4	6	9
2	16	22	13	22	13	19	11	16
3	75	72	62	67	54	60	50	61
4	9	5	22	10	29	16	33	15
	4 August		11 August		21 August			
Dead	10	12	12	16	13	18		
2	9	13	8	12	7	11		
3	47	57	46	53	46	52		
4	34	18	34	18	34	18		

Soil water potential declined together with leaf water potential over the summer of 1984, but there was no indication that clump-1 plants behaved differently than clump-4 plants (fig. 5). Shrubs in the large-plant blocks reduced soil water potential to a minimum of -1.2 MPa while shrubs in the other blocks reduced soil water potential to 0.6 MPa. Also, the decline in leaf water potential per unit decline in soil water potential at 50 cm was lower in the large-plant blocks. These observations may have resulted from higher rooting density at 50 cm under the larger shrubs, causing daily equilibrium between plant and soil at dawn to become more fully established. The considerable scatter in the data contrasts with the results of Sala and others (1981) who found a very close relationship between water potential in the wettest soil layer and predawn leaf water potential. Perhaps, the 50-cm depth at which we measured soil water potential was not always the wettest part of the soil profile. Branson and others (1976) found that plant water potential in big sagebrush was highly correlated with minimum soil water potential, but under moist conditions factors other than soil moisture appeared to exert control over plant water potential.

If differences in soil-plant water relations were to materialize, they would have little effect on production if the differences did not substantially affect net carbon assimilation of big sagebrush. DePuit and Caldwell (1973, 1975) found that net photosynthesis in big sagebrush was strongly affected by plant water potential. They found that net photosynthesis was much greater for plants in the "emergent new leaves" and "rapid vegetative growth" phenological stages than for the later stages of "reduced vegetative growth" and "reproductive shoots full size." Thus, if major differences in leaf water potential developed between clump-1 and clump-4 big sagebrush plants only after they had passed through the rapid vegetative growth phenological stage, little difference in seasonal production between the clump types should occur.

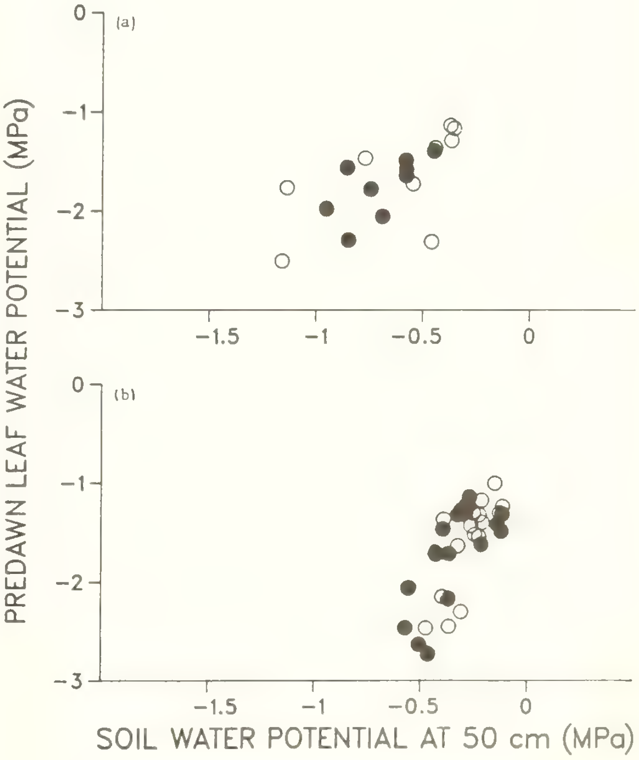

Figure 5-- Soil-plant water relationship for clump-1 and clump-4 plots under plants during May-August 1984. (a) Large-plant blocks, and (b) medium- and small-plant blocks. Clump-1 data are denoted by open symbols; clump-4 data are denoted by closed symbols.

We attribute part of the lack of observed effects of clump type on soil or leaf water potential to the abundant precipitation during 1981-1984. Three successive wet years probably meant that the soil profile was completely saturated to the maximum rooting depth of the big sagebrush plants at the beginning of the 1983 and 1984 growing seasons. In addition, the elimination of weeds in the plots meant that some soil water which would have been transpired by the weeds was available to the big sagebrush plants.

During the summer of 1983, the longest "dry" period lasted from June 5 to August 16, although numerous small rain showers, including an 8-mm event on July 2, occurred in that interval. During the summer of 1984, the longest "dry" period ran from June 7 to July 20, including an 8-mm event on July 9. Perhaps, it is not surprising that major differences in soil and leaf water potentials between clump types failed to appear.

An additional factor that may have eliminated treatment effects relates to the increase in shrub size during the study. As the shrubs grew from 1982-84, the scale of snow trapping behavior may have changed. Tabler and Schmidt (1985) proposed that snow deposition around shrubs follows the relationship: $S = H - 0.01\ A\ D^{-1}$. Here, S = snow depth, H = height of shrub above the ground, A = shrub surface area normal to the prevailing wind, and D = shrub width or diameter. When the shrubs were small, canopies did not overlap even in the clumps of four. If plants in the clump-1 and clump-4 plots had about the same average heights and widths, the amount of snow trapped should have been about the same.

However, by the end of 1983, each clump-1 plot could be regarded as a large cluster. Shrub canopies in the clump-1 plots did not overlap, and shrub density was nearly optimal for snow trapping (Tabler and Schmidt 1985). On the other hand, plants in the clump-4 plots had dense, intermingled canopies. These clumps could be regarded as large single plants in terms of their snow trapping ability, but the clumps were not as wide as the summed widths of four single shrubs. Tabler and Schmidt (1985) also noted that dense canopies, as in the clumps of four, are less efficient snow trappers than more diffuse canopies, as in the clump-1 plants. These factors could have reduced snow trapping in the clump-4 plots compared to the clump-1 plots in the winter of 1983-84.

REFERENCES

Allen, M. F.; Allen, E. B.; West, N. E. 1987. Influence of parasite and mutualistic fungi on temperate semi-desert shrubs. Bulletin of the Torrey Botanical Club (in press).

Anderson, D. L.; Jacobs, S. W. L.; Malik, A. R. 1969. Studies on structure in plant communities. VI. The significance of pattern evaluation in some Australian dry-land vegetation types. Australian Journal of Botany. 17: 315-322.

Andrew, M. H.; Noble, I. R.; Lange, R.T. 1979. A non-destructive method for estimating the weight of forage on shrubs. Australian Rangeland Journal. 1:225-231.

Andrew, M. H.; Noble, I. R.; Lange, R. T.; Johnson, A. W. 1981. The measurement of shrub forage weight: three methods compared. Australian Rangeland Journal. 3: 74-82.

Barbour, M. G.; Diaz, D. V. 1973. *Larrea* plant communities on bajada and moisture gradients in the United States and Argentina. Vegetatio. 28: 335-352.

Barbour, M. G.; MacMahon, J. A.; Bamberg, S. A.; Ludwig, J. A. 1977. The structure and distribution of *Larrea* communities. In: Mabry, T. G.; Hunziker, J. H.; DeFeo, D. R., Jr., eds. Creosote bush: biology and chemistry of *Larrea* in the New World deserts. Stroudsbury, PA: Dowden, Hutchinson, and Ross, Inc.: 227-251.

Beals, E. W. 1968. Spatial pattern of shrubs on a desert plain in Ethiopia. Ecology. 49: 744-746.

Beetle, A. A. 1960. A study of sagebrush--the section *Tridentatae* of *Artemisia*. Bulletin 368. Laramie, WY: Wyoming Agricultural Experiment Station. 83 p.

Branson, F. A.; Miller, R. F.; McQueen, J. S. 1976. Moisture relationships in twelve northern desert shrub communities near Grand Junction, Colorado. Ecology. 57: 1104-1124.

Brown, R. W.; Bartos, D. L. 1982. A calibration model for screen-caged Peltier themocouple psychrometers. Res. Pap. INT-293. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 155 p.

Carpenter, A. T.; West, N. E. 1987. Validating the reference unit method of above-ground phytomass estimation. Vegetatio. (in press).

Charley, J. L.; West, N. E. 1975. Plant induced soil chemical patterns in shrub-dominated semi-desert ecosystems in Utah. Journal of Ecology. 63: 945-964.

DePuit, E. J.; Caldwell, M. M. 1973. Seasonal patterns of net photosynthesis of *Artemisia tridentata*. American Journal of Botany. 60: 426-435.

DePuit, E. J.; Caldwell, M. M. 1975. Gas exchange of three cool semi-desert species in relation to temperature and water potential. Journal of Ecology. 63: 835-858.

Ehleringer, J. E. 1984. Intraspecific competitive effects on water relations, growth, and reproduction in Encelia farinosa. Oecologia. 63: 153-158.

Fonteyn, P. J.; Mahall, B. E. 1978. Competition among desert perennials. Nature. 275: 544-545.

Fonteyn, P. J.; Mahall, B. E. 1981. An experimental analysis of structure in a desert plant community. Journal of Ecology. 69: 883-896.

Friedman, J.; Orshan, G. 1975. The distribution, emergence and survival of seedlings of Artemisia herba-alba Asso in the Negev Desert of Israel in relation to distance from the adult plants. Journal of Ecology. 63: 627-632.

Garcia-Moya, E.; McKell, C. M. 1970. Contributions of shrubs to the nitrogen economy of a desert-wash plant community. Ecology. 51: 81-88.

Greig-Smith, P.; Chadwick, M. J. 1965. Data on pattern within plant communities. III. Acacia-Capparis semi-desert shrub in the Sudan. Journal of Ecology. 53: 465-474.

Hunt, R. 1978. Plant growth analysis. London: Edward Arnold.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54: 187-211.

MacMahon, J. A.; Schimpf, D. J. 1981. Water as a factor in the biology of North American desert plants. In: Evans, D. D.; Thames, J. L., eds. Water in desert ecosystems. Stroudsburg, PA: Dowden, Hutchinson and Ross, Inc.: 114-171.

Malik, A. R.; Anderson, D. J.; Myerscough, P. J. 1976. Studies on structure in plant communities. VII. Field and experimental analysis of Atriplex vesicaria populations from the Riverine Plain of New South Wales. Australian Journal of Botany. 24: 265-280.

National Oceanic and Atmospheric Administration. 1982. Monthly normals of temperature and precipitation and heating and cooling degree days 1951-1980--Wyoming. Asheville, NC.

Phillips, D. L.; MacMahon, J. A. 1981. Competition and spacing patterns in desert shrubs. Journal of Ecology. 69: 97-115.

Robberecht, R.; Mahall, B. E.; Nobel, P. S. 1983. Experimental removal of intraspecific competitors--effects on water relations and productivity of a desert bunchgrass, Hilaria rigida. Oecologia. 60: 21-24.

Rodriguez, J. C. 1985. Rooting observations in revegetated land: vertical distribution with layered overburden and topsoil. Logan, UT: Utah State University. M.S. Thesis.

Sala, D. E.; Lauenroth, W. J.; Parton, W. J.; Trlica, M. J. 1981. Water status of soil and vegetation in a shortgrass steppe. Oecologia. 48: 327-331.

Sturges, D. L. 1977. Soil water withdrawal and root characteristics of big sagebrush. American Midland Naturalist. 98: 257-274.

Tabler, R. D. 1964. The root system of Artemisia tridentata at 9,500 feet in Wyoming. Ecology. 45: 633-636.

Tabler, R. D.; Schmidt, R. A. 1985. Snow erosion, transport and deposition in relation to agriculture. Symposium on snow transport. 9-11 July 1985. Swift Current, Saskatchewan.

Waisel, Y. 1971. Patterns of distribution of some xerophytic species in the Negev, Israel. Israel Journal of Botany. 20: 101-110.

West, N. E. 1983. Western Intermountain sagebrush steppe. In: West, N. E., ed. Temperate deserts and semi-deserts. Amsterdam: Elsevier: 351-374.

West, N. E. 1987. Spatial pattern-functional interactions in shrub dominated plant communities. In: McKell, C. M., ed. Shrub biology and utilization. Academic Press, New York.

West, N. E.; Goodall, D. W. 1986. Dispersion patterns in relation to successional status of salt desert shrub vegetation. Abstracta Botanica. 10: 187-201.

Williams, D. G.; Anderson, D. G.; Slater, K. R. 1978. The influence of sheep on pattern and process in an Atriplex vesicaria population from Riverine Plain of New South Wales. Australian Journal of Botany. 26: 381-392.

Woodell, S. R. J.; Mooney, H. A.; Hill, A. J. 1969. The behavior of Larrea divaricata (creosote bush) in response to rainfall in California. Journal of Ecology. 57: 37-44.

STOMATAL SENSITIVITY AND WATER-USE EFFICIENCY IN OAKS AND THEIR HYBRIDS

James R. Ehleringer and Mark P. Smedley

ABSTRACT: The sensitivities of stomata to changes in the leaf to air water vapor gradient (Δw) were measured on oaks (Quercus gambelii, Q. macrocarpa, and Q. turbinella) and their hybrids growing under common field conditions in the Cottam Oak Hybrid Grove at the University of Utah. The ranking order for decreasing sensitivity of leaf gas exchange to changes in Δw was Q. turbinella, Q. gambelii, and Q. macrocarpa. In addition, leaf carbon isotope ratios, an indicator of long-term water-use efficiency, were measured on these same plants. These data suggest that leaf water-use efficiencies are lowest in Q. gambelii and higher in both Q. macrocarpa and Q. turbinella.

STOMATA AND HUMIDITY

Stomata serve to regulate the diffusion of water vapor out of a leaf and carbon dioxide into the leaf and thus play a primary role in controlling both photosynthesis and transpiration. It is now well known for a large number of species that the stomata of leaves are sensitive to changes in the leaf to air water vapor gradient (Δw), independent of changes in bulk leaf water status (Lange and others 1971; Schulze and Hall 1982). This response, often referred to as the stomatal sensitivity to humidity, is usually measured as the decrease in the leaf conductance to water vapor diffusion as the air becomes progressively drier. While numerous studies have documented differences in the stomatal sensitivity to humidity among species, few have attempted to correlate this parameter with plant performance or with plant distribution.

In their review, Schulze and Hall (1982) suggested that there was no systematic trend in stomatal sensitivity to Δw other than that those species which had the highest leaf conductances seemed to show the greatest absolute decrease in leaf conductance with increasing Δw. On the other hand, Losch (1979) and Losch and Tenhunen (1981) suggested in their reviews that although complete data sets were lacking there appeared to be a greater stomatal sensitivity to humidity in plants adapted to dry sites than in plants adapted to wetter sites. Furthermore, they suggested that these differential sensitivities resulted in different rates of carbon gain in respective habitats and ultimately affected plant distributions. As evidence of this, Johnson and Caldwell (1976) compared stomatal sensitivity to increased Δw in four alpine tundra species, two adapted (=restricted ?) to wet, moist sites and two adapted to drier, drained slopes. The stomates of the species adapted to wet sites were only slightly sensitive to decreased humidity, whereas leaf conductances of species from dry habitats decreased quickly in response to an increase in Δw. Supporting evidence for this pattern can also be seen in the comparative study of two Diplacus aurantiacus populations from coastal and inland habitats by Mooney and Chu (1983). In that study, leaves of plants of the population from the drier locations again had stomata that were more sensitive to changes in humidity than leaves of plants from the wetter habitat population.

GAS EXCHANGE AND WATER-USE EFFICIENCY

Since limited water availability is of major concern for the cultivation of crop plants and as well appears to limit the productivity of most if not all native plants, it is not too surprising that for many years there has been an intense interest in trying to understand how leaves simultaneously regulate carbon dioxide uptake and transpirational water loss (Tanner and Sinclair 1983; Sinclair and others 1984). Photosynthetic rates (A) tend to decline in response to a decreased leaf conductance (g), because carbon dioxide diffusion rates into the leaf and hence intercellular carbon dioxide concentrations (c_i) are progressively reduced with a reduction in leaf conductance. However, if leaf temperatures do not change substantially as the stomata close, there may be an increase in the water-use efficiency (molar ratio of photosynthesis to transpiration).

The rate of net photosynthesis as influenced by stomatal activity can be described as:

$$A = (c_a - c_i)\, g/1.6 \qquad (1)$$

and the transpiration rate (E) as

$$E = \Delta w\, g \qquad (2)$$

where c_a is the atmospheric carbon dioxide concentration and 1.6 is the ratio of the diffusivities of water to carbon dioxide in air and is used to convert the conductance to water vapor through the stomata to the conductance to carbon dioxide through the stomata.

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James R. Ehleringer is Professor of Biology and Mark P. Smedley is Graduate Student of Biology, University of Utah, Salt Lake City.

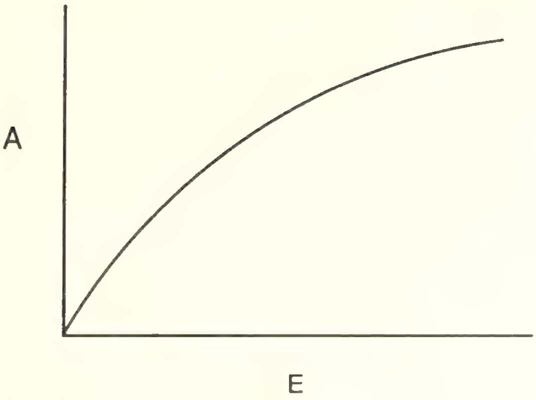

Figure 1--The relationship between net photosynthesis (A) and transpiration (E).

Combining these two equations we see that the water-use efficiency (A/E) becomes

$$A/E = (c_a - c_i)/(1.6\ \Delta w) \qquad (3)$$

Thus, under natural field conditions the leaf water-use efficiency depends on both the intercellular carbon dioxide concentration and the leaf to air water vapor gradient.

For a given decrease in stomatal or leaf conductance, the water-use efficiency of a leaf is typically increased (assuming leaf temperature remains constant). This is because a unit decrease in leaf conductance has a smaller impact on photosynthetic rate than it does on transpiration rate. In Figure 1, the relationship between A and E is plotted. Note that the relationship is curvilinear and that the slope of this relationship, which is water-use efficiency, decreases as the flux rates increase. The decrease in photosynthesis with decreased leaf conductance is best visualized by examining the dependence of net photosynthesis on intercellular CO_2 and the role that leaf conductance plays in regulating c_i values (Figure 2). While a unit decrease in leaf conductance results in a unit decrease in transpiration rate, its impact is smaller on photosynthesis because the A vs. c_i response curve is usually nonlinear and has a nonzero intercept on the x-axis (that is C_3 plants have a positive compensation point). In our analyses, we have assumed that the A vs c_i response curves were similar among the different oak species; preliminary data on leaf amino nitrogen contents of these species are supportive of this assumption (Ehleringer, Hogle and Blackmore, unpublished observations).

CARBON ISOTOPE RATIO

Measuring leaf water-use efficiency over long time periods has been difficult because of the necessity to simultaneously measure biomass production and water consumption in a nondestructive manner. However, Farquhar, O'Leary and Berry (1982b) first proposed an alternative means of estimating leaf water-use

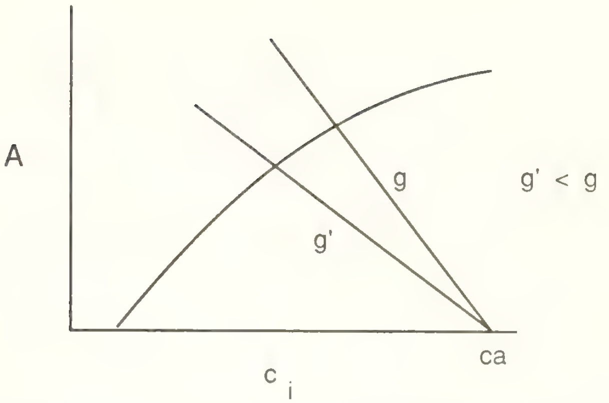

Figure 2--The dependence of net photosynthesis (A) on intercellular CO_2 concentration (c_i), often referred to as the "demand function" for photosynthesis. The linear lines represent the leaf conductance to CO_2 diffusion through the stomata, often referred to as the "supply function". The intersection of the demand and supply functions is the operational point, given those leaf characteristics. In this figure g > g', so that the reduced leaf conductance of g' results in a lower intercellular CO_2 concentration and thus also a lower photosynthetic rate.

efficiencies using carbon isotope ratios at natural abundance levels.

The carbon isotope ratio ($\delta^{13}C$) is the ratio of the $^{13}C/^{12}C$ composition of a sample (R_{sample}) relative to the $^{13}C/^{12}C$ composition of a standard (R_{std}),

$$\delta^{13}C = (R_{sample}/R_{std} - 1)\ 1000 \qquad (4)$$

where $\delta^{13}C$ has units of parts per mil (o/oo) and represents the deviation in composition of the sample from the standard, a fossil belemnite from the Pee Dee Formation (PDB).

Farquhar and others (1982b) proposed that there should be a relationship between the average c_i during the photosynthetically active period and $\delta^{13}C$. Their idea is based upon two observations: first $^{13}CO_2$ in air diffuses more slowly than $^{12}CO_2$, and second, that RuBP carboxylase, the initial carboxylating enzymatic reaction of photosynthesis in C_3 plants will discriminate against $^{13}CO_2$. While RuBP carboxylase can discriminate against $^{13}CO_2$, it does so only as a function of CO_2 levels actually at the sites where carboxylation is occurring (i.e., c_i level). Thus, it is predicted that

$$\delta^{13}C_{leaf} = \delta^{13}C_{air} - a - (b-a)\ c_i/c_a \qquad (5)$$

where a is the discrimination due to diffusion differences (4.4 o/oo) and b is the discrimination due to RuBP carboxylase (27 o/oo). A number of data sets exist which verify the expected relationships between $\delta^{13}C$ and intercellular CO_2 (Farquhar and others 1982a; Bradford and others 1983; Ehleringer and others 1985).

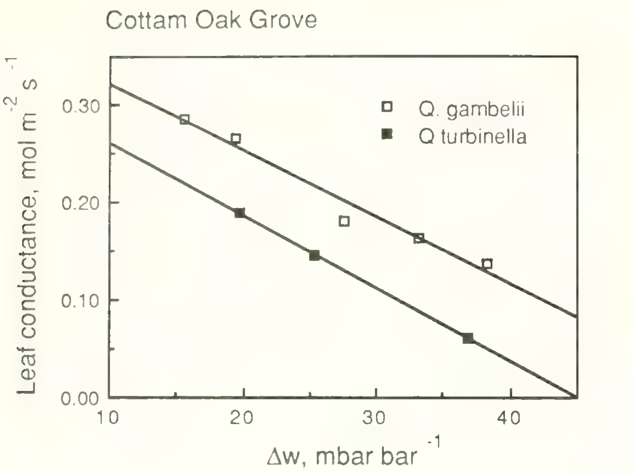

Figure 3--The dependence of leaf conductance to water vapor on the leaf to air water vapor gradient (Δw) for leaves of *Quercus gambelii* and *Quercus turbinella* under common field conditions in the Cottam Oak Hybrid Grove at the University of Utah.

The advantage of using stable isotopes is that since carbon is continually being fixed by a leaf, measuring the carbon isotope ratio of a leaf provides a long-term indication of c_i. Therefore, carbon isotope ratio is useful as a long-term indicator of leaf-water use efficiency (assuming leaf temperatures are held constant). Since various environmental factors (such as drought, temperature, salinity) influence gas exchange and thus c_i, carbon isotope ratios can be used to estimate how water-use efficiency changes in response to a diversity of environmental conditions.

OAKS IN THE COTTAM OAK HYBRID GROVE

In the 1960's Dr. Walter Cottam of the University of Utah began assembling a diversity of oak species from North America, Europe and Asia for experimental studies (Cottam, Tucker and Santamour 1982). His interest was in producing and examining various hybrid combinations, some of which might naturally arise in zones where the species naturally overlapped in distribution. Parents and hybrids from his studies have now been established for many years at an experimental garden (Cottam Oak Hybrid Grove) adjacent to the University of Utah campus.

In this paper, we examine the stomatal characteristics and carbon isotope ratios of three of the oaks, *Quercus gambelii*, *Q. macrocarpa*, and *Q. turbinella* and their hybrids. We have chosen these species as they represent the three most important oak species in the intermountain west, they occur in habitats of contrasting aridity and water availability, and in areas of overlap do indeed form hybrid zones.

The three oak species occur in contrasting ecological zones. *Q. gambelii* has deciduous leaves and occurs in relatively mesic zones between grassland and coniferous forests, primarily in northern Arizona, Colorado and Utah. In the drier, more southern portions of Arizona, California, New Mexico and Utah, *Q. gambelii* is replaced by the evergreen-leaved species *Q. turbinella*. *Q. macrocarpa* occurs on the eastern margins of the intermountain west and its distribution extends across much of the Great Plains region. It is a deciduous-leaved species, effectively restricted to riparian habitats.

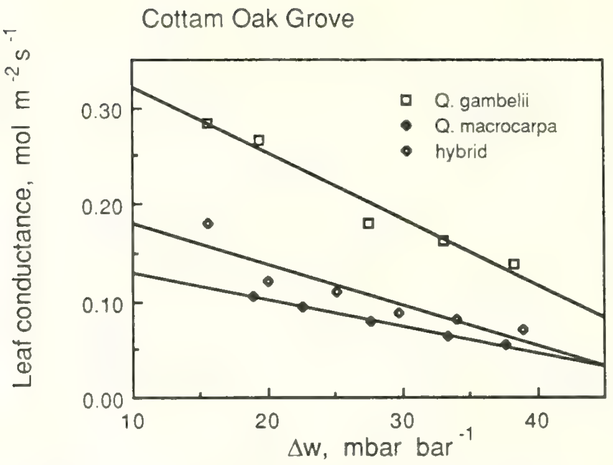

Figure 4--The dependence of leaf conductance to water vapor on the leaf to air water vapor gradient (Δw) for leaves of *Quercus gambelii*, *Quercus macrocarpa* and hybrids under common field conditions in the Cottam Oak Hybrid Grove at the University of Utah.

STOMATAL SENSITIVITY TO HUMIDITY IN OAKS

Stomatal responses to changes in humidity between a Δw of 20 and 40 mbar bar^{-1} were essentially linear in all oak species examined. The major differences between species were due to changes in the slopes and intercepts of these relationships. The stomata of *Q. turbinella* were more sensitive to changes in Δw than were the stomata of either *Q. gambelii* or *Q. macrocarpa* (Figures 3-4). On average the change in leaf conductance per unit change in Δw ($\delta g/\delta \Delta w$) was -0.077, -0.066, and -0.024 for the three species respectively (Tables 1-2).

In the crosses between *Q. gambelii* and *Q. turbinella*, the performance of the hybrids was reduced below that of either parent (Table 1). Both the slope and intercept of the leaf conductance versus Δw response curve were very much lower in magnitude.

For the crosses between *Q. gambelii* and *Q. macrocarpa*, the stomatal behavior of the hybrids was intermediate between that of the parents (Table 2). Both the slope and the intercept of the leaf conductance versus Δw response curve were intermediate between the two parents.

There was no significant correlation among species and hybrids between the slope and

Table 1--Mean slope (mol bar $mbar^{-1}$ m^{-2} s^{-1}) and intercept (mol m^{-2} s^{-1}) values for the dependence of leaf conductance to water vapor on the leaf to air water vapor gradient (Δw) for Q. gambelii, Q. turbinella and hybrids between them growing in the Cottam Oak Hybrid Grove at the University of Utah

	Q. gambelii	Q. gambelii x turbinella	Q. turbinella
slope	-0.066	-0.0030	-0.077
intercept	0.380	0.275	0.350

Table 2--Mean slope (mol bar $mbar^{-1}$ m^{-2} s^{-1}) and intercept (mol m^{-2} s^{-1}) values for the dependence of leaf conductance to water vapor on the leaf to air water vapor gradient (Δw) for Q. gambelii, Q. macrocarpa and hybrids between them growing in the Cottam Oak Hybrid Grove at the University of Utah

	Q. gambelii	Q. gambelii x macrocarpa	Q. macrocarpa
slope	-0.066	-0.0042	-0.024
intercept	0.380	0.224	0.157

intercept of the leaf conductance versus Δw response curve. The independence of these two characters suggests that leaves of species with intrinsically higher gas exchange rates are not necessarily more sensitive to changes in Δw than leaves of species with lower gas exchange rates.

WATER-USE EFFICIENCY IN OAKS

There was a large intraspecific variation in long-term water-use efficiencies as indicated by leaf carbon isotope ratios for both Q. gambelii and Q. turbinella (Figure 5). For both species, there was slightly more than a 2 o/oo range in carbon isotope ratios values. This suggests that mean ci values among genotypes of each species differed by more than 30 μl 1-1. Unfortunately as there was only a single Q. macrocarpa tree within the experimental garden, it is not possible to say much about the variation within this species.

The impact of the changes in ci on actual water-use efficiency will depend on the atmospheric humidity conditions. If we assume typical daytime summer values for Salt Lake City of 32 C for both air and leaf temperatures and a 20% relative humidity, then the calculated change in water-use efficiency in going from a carbon isotope ratio of -27 o/oo to -25 o/oo is an increase of 25%, increasing from an absolute value of 1.47 to 1.84. Thus, there would appear to be substantial genetic variation in water-use efficiency within oak genotypes. The implications of these differences in water-use efficiency to long-term plant performance are not understood at this time.

The hybrids growing in the Cottam Oak Grove also exhibited a wide variation in leaf carbon isotope ratios (Figures 5-6). For the crosses between Q. gambelii and Q. turbinella, there was as much isotopic variation as in each of the parents and the values overlapped completely with the range of Q. turbinella. However, for the Q. gambelii and Q. macrocarpa crosses, even though the range of leaf isotope ratios of the hybrids was similar to the parents (at least of the Q. gambelii parent), the mean isotope ratios were intermediate between those of the two parents (given the limited data available for Q. macrocarpa).

CORRELATIONS BETWEEN WATER RELATIONS AND OAK DISTRIBUTION

In the intermountain west, Q. gambelii occupies wetter, higher elevation sites than does Q. turbinella. It is then not too surprising to note that leaf carbon isotope ratio data suggest that water-use efficiency is higher in Q. turbinella than in Q. gambelii. What is perhaps surprising is the observation that water-use efficiency in Q. macrocarpa, a species which occupies riparian habitats is so much higher than that of Q. gambelii. Whether these differences are due to water conditions in the experimental garden or whether Q. macrocarpa has an intrinsically higher water-use efficiency is unclear at this time. The leaf carbon isotope ratio data for the Q. gambelii x macrocarpa and Q. macrocarpa x gambelii hybrids do suggest that Q. macrocarpa may indeed have a higher water-use efficiency under natural field conditions.

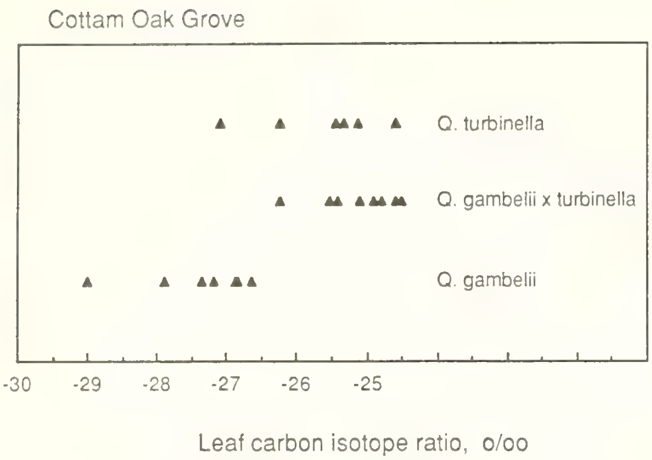

Figure 5--Leaf carbon isotope ratios for leaves of different individual trees of Quercus gambelii, Quercus turbinella, and hybrids between them at the Cottam Oak Hybrid Grove.

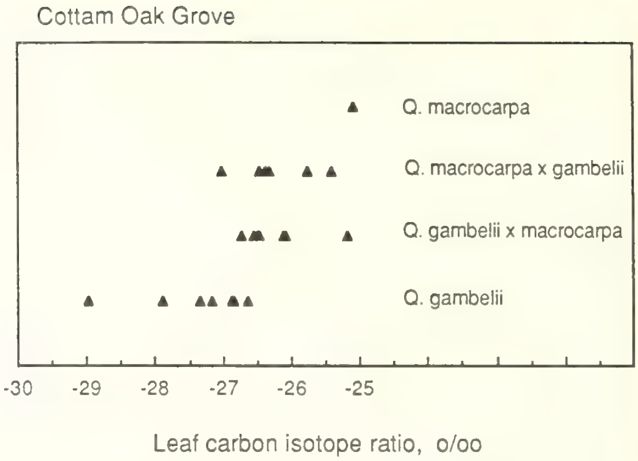

Figure 6--Leaf carbon isotope ratios for leaves of different individual trees of Quercus gambelii, Quercus macrocarpa, and hybrids between them at the Cottam Oak Hybrid Grove.

REFERENCES

Bradford, K. J.; Sharkey, T. D.; Farquhar, G. D. 1983. Gas exchange, stomatal behavior and δ^{13}C values of the flacca tomato mutant in relation to abscisic acid. Plant Physiology. 72: 245-250.

Cottam, W. P.; Tucker, J. M.; Santamour, F. S., Jr. 1982. Oak Hybridization at the University of Utah. State Arboretum of Utah Publication No. 1.

Ehleringer, J. R.; Schulze, E. -D.; Ziegler, H.; Lange, O. L.; Farquhar, G. D.; Cowan, I. R. 1985. Xylem-tapping mistletoes: water or nutrient parasites? Science. 227: 1479-1481.

Farquhar, G. D.; Ball, M. C.; von Caemmerer, S.; Roksandic, Z. 1982a. Effect of salinity and humidity on δ^{13}C value of halophytes - evidence for diffusional isotope fractionation determined by the ratio of intercellular/atmospheric partial pressure of CO$_2$ under different environmental conditions. Oecologia. 52: 121-124.

Farquhar, G. D.; O'Leary, M. H.; Berry, J. A. 1982b. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Australian Journal of Plant Physiology. 9: 121-127.

Johnson, D. A.; Caldwell, M. M. 1976. Water potential components, stomatal function, and liquid phase water transport resistances of four arctic and alpine species in relation to moisture stress. Physiologia Plantarum. 36: 271-278.

Lange, O. L.; Losch, R.; Schulze, E. -D.; Kappen,L. 1971. Responses of stomata to changes in humidity. Planta. 100: 76-86.

Losch, R. 1979. Stomatal responses to changes in humidity. In: Sen, D. N., Chawan, D. D., Bansal, R. P., eds., Structure, Function, and Ecology of Stomata; Dehra Dun: 189-216.

Losch, R.; Tenhunen, J. D. 1981. Stomatal responses to humidity - phenomenon and mechanism. In: Jarvis, P. G., Mansfield, T. A., eds., Stomatal Physiology; Cambridge: Cambridge University Press: 137-161.

Mooney, H. A.; Chu, C. 1983. Stomatal responses to humidity of coastal and interior populations of a Californian shrub. Oecologia. 57: 148-150.

Schulze, E. -D.; Hall, A. E. 1982. Stomatal responses, water loss and CO$_2$ assimilation rates of plants in contrasting environments. In: Lange, O. L., Nobel, P. S., Osmond, C. B., Ziegler, H., eds., Physiological Plant Ecology II. Encyclopaedia of Plant Physiology, New Series; Berlin, Springer Verlag: 181-230.

Sinclair, T. R.; Tanner, C. B.; Bennett, J. M. 1984. Water-use efficiency in crop production. BioScience. 34: 36-40.

Tanner, C. B.; Sinclair, T. R. 1983. Efficient water use in crop production: research or re-search? In: Taylor, H. M., Jordan, W. R., Sinclair, T. R., eds., Limitations to Efficient Water Use in Crop Production; Madison, American Society of Agronomy: 1-27.

PLANT ECOPHYSIOLOGY: A CASE STUDY OF HONEY MESQUITE

R. E. Sosebee and C. Wan

ABSTRACT: Plant ecophysiology is often used interchangeably with "environmental physiology" and "physiological ecology". Ecophysiology is primarily concerned with "the physiology of plants as it is modified by fluctuating external influences". Species and ecotypes within species have their ranges of ecological adaptation based upon the physiological constitution of the plants. Xerophytes respond to the environmental conditions of their natural habitat similarly to mesophytes in their habitat.

Honey mesquite is a facultative phreatophyte. Its consumptive water use is very opportunistic. Transpiration rates and duration of transpiration are greater on wet sites than on dry sites. Predawn leaf water potentials are substantially higher in trees growing on wet sites (-12 bars) than in those on dry sites (-24 bars) during the summer drought. Photosynthetic rates are also higher in trees growing on wetter sites. Soil temperature influences growth and development of mesquite. Optimum temperature for root growth appears to be about 27°C. At sub-optimum temperatures (21°C) niacin appears to be limiting root growth and at supra-optimum temperatures (32°C) thiamine appears to be limiting. Mesquite anatomy responds to environmental changes. As the growing season progresses and the environment becomes hotter and drier, the leaves develop a thickened epidermal cell wall that reduces evapotranspirational water loss.

Native plants are well adapted to the environment in which they have evolved. Their physiological mechanisms allow them to take advantage of the existing conditions. All species (and all ecotypes or populations within a species) do not respond to the same environment in the same manner. The physiological response of each species and ecotype should be evaluated for each environment in which the plant grows to fully understand its ecophysiology.

INTRODUCTION

Plant "ecophysiology" is often used interchangeably with "environmental physiology" and "physiological ecology" depending upon one's background (Tracy and Turner 1982). Plant ecophysiology is primarily concerned with "the physiology of plants as it is modified by fluctuating external influences" (Larcher 1980). Emphasis of physiological relationships in plant ecology is not new. Schimper (1898) was one of the first to suggest that ecological relationships be approached from a physiological viewpoint. Tansley (1914) suggested that the most fundamental problems of plant ecology were physiological and called for the formation of a School of Physiological Ecology to address the basic issues of ecology.

The physiological approach to ecological problems seems to have been largely abandoned until the 1960's. In 1962 an international symposium was held in Montpellier, France to address ecophysiological problems of arid zone research (Eckardt 1965). This symposium served as the springboard for renewed interest in plant ecophysiology or physiological ecology. Since the mid 1960's, there has been a major emphasis on plant ecophysiology.

"Normal" and "extreme" ranges of environmental factors vary in time and space. The diversity of species exploiting any particular environment reflects specific adaptations of the species. The nature of these adaptations must be examined in view of the plant's physiological ability to respond to the environment (Fitter and Hay 1981). Favorable environmental conditions are not necessarily determined by regional climates or even microclimates. Adaptability is determined by the environment in which the vital processes take place within the protoplasm (Walter 1973). Largely, a plant's adaptability to specific environments depends upon its enzyme and membrane responses to the internal conditions created by the external environment.

This presentation is intended as an overview of plant ecophysiology. Time and space do not permit a thorough treatise on plant ecophysiology. Everyone has a basic understanding of plant ecological and physiological processes; therefore, specific examples will be drawn from honey mesquite (Prosopis glandulosa) on how a plant responds physiologically to its environment.

One of the common mistakes made by plant physiologists and plant ecologists is assuming that all populations within a species respond similarly to all environments within the species'

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Ronald E. Sosebee is Professor of Range Management and Changgui Wan is Graduate Research Assistant, Department of Range & Wildlife Management, Texas Tech Univeristy, Lubbock, Texas, 79409. Contribution No. T-9-502, College of Agricultural Sciences, Texas Tech University.

range. Turresson (1922a, 1922b) demonstrated differences among populations within a species according to habitat differences which he called ecotypes. Classical ecotypic differentiation within Achillia and Potentilla has been shown by Clausen and others (1940). Since the early 1940's others have shown ecotypic differentiation within a number of species (McNaughton 1966, McNaughton 1967, McNaughton 1972, Davies and Snaydon 1973a, Davies and Snaydon 1973b, Davies and Snaydon 1974, Goodman and Caldwell 1971, Musselman and others 1975, Vickery 1950, Wilkinson 1980, Whalley and Burfitt 1972, Wooten 1973, and Workman and West 1969). Ecotypes may or may not be morphologically distinct, but they are genetically different. They respond differently to similar environmental regimes according to their physiological capabilities.

Ecotypic variation in mesquite has only briefly been addressed. Prosopis has a wide distribution ranging from much of North and South America, to North Africa and the Middle East (Simpson and Solbrig 1977). Ecotypic variation was demonstrated among North American species by Peacock and McMillan (1965). They showed that populations of P. glandulosa responded to photoperiod, thermoperiod, and length of growing season according to the latitude from which they were collected. McLendon (1979) further showed that edaphic ecotypes exist within Prosopis glandulosa. It is important for scientists to realize that plants within a species will have different physiological responses to an environment depending upon their evolutionary history. If one chooses to undertake an ecophysiological study of a species, he must first identify the environment which that species inhabitats.

SEEDS AND SEEDLINGS

Physiological response to any environment varies seasonally, annually, and throughout the life cycle of the plant. Mature seeds are the most resistant organs to environmental change; however, maturation of fruits and seeds is quite vulnerable to environmental conditions.

Germination of seeds and establishment of seedlings depends upon several factors. Harper and others (1961) have referred to the summation of these factors as "safe sites". Safe sites imply adequate water, appropriate temperatures and light, and sufficient space are available for germination to occur and seedlings to be established.

Soil temperature and water potentials are critical to the germination process. Water is essential to initiate germination. Seeds of native, wildland plants have a very low water content (<15%) and will remain dormant until the environment receives adequate water to assure the germination process (McDonough 1977). When sufficient water is received, as perceived by the seed resulting from scarification, leaching inhibitors, etc., imbition will occur releasing gibberellic acid from the aleurone layer in the seedcoat initiating the biochemical reactions of the germinating process. Amount of water required for germination varies among species depending upon their adaptations. However, there is a minimum threshold in water content that must be surpassed before germination will begin. After germination is initiated, a minimum amount of water must be maintained in the environment to insure completion of the germination process and establishment of the seedlings. Several scientists (Wester and others 1986, Frasier and others 1985) have illustrated the importance of continuous soil moisture in establishment of kleingrass (Panicum coloratum), weeping lovegrass (Eragrostis curvula), Lehmann lovegrass (E. lehmanniana) and "Cochise" lovegrass (E. lehmannianas E. trichophora. Their research pointed out that the amount of soil water is not as important to germination and establishment as the constancy of the supply. Much research in Colorado (Hyder and others 1971, Wilson 1971, Hyder and others 1976, Wilson and others 1976, Briske and Wilson 1977, Briske and Wilson 1978, Wilson and Sailes 1978, Wilson and Briske 1979, Briske and Wilson 1980, and Fulbright and others 1985), illustrates the importance of soil water in establishment of blue grama (Bouteloua gracilis), crested wheatgrass (Agropyron cristatum) and green needlegrass (Stipa viridula).

Usually, plants adapted to drier climates develop an extensive root system before shoot growth begins. A sand shinnery oak radicle will easily be two-feet long before the cotyledons emerge from the seed (R. D. Pettit, personal communication). Mesquite undergoes similar development phases in the germination process (Mooney and others 1977). Root development in both P. velutina and P. glandulosa greatly exceeds shoot development.

Soil temperature is also very important in germination and seedling establishment of mesquite. High soil temperatures hinder seedling establishment as well as low temperatures. Grass and shrub seeds have very low germination and establishment rates under high temperature regimes such as those found in the desert southwest. Reduction of soil temperature from an average of 40°C, or higher, to 26°C increased establishment of fourwing saltbush (Atriplex canescens), sacaton (Sporobolus wrightii), vine mesquite (Panicum obtusum), and bush muhly (Muhlenbergia porteri) (Sosebee and Herbel 1967).

Optimum temperature for germination of mesquite seeds is 85°F and the minimum threshhold is 77°F; germination was reduced at 100°F (Haas and others 1973). Amount of soil water required for germination varied according to the soil temperature; less water was required for germination at 85°F than at either 70° or 100°F (Haas and others 1973). Germination rates were not reduced by water potentials of 8 atm, as long as the temperature was 85°F. Water stress apparently occurred at 100°F, whereas, temperature adversely affected germination at 70°F.

Light is an important influence in seed germination. Early successional plants are often classified as r-selected species which refers to an intrinsic rate of natural increase; whereas, climax plants are classified as K-selected species (Barbour and others 1987). The r-selected plants usually are adapted to high light regimes and require light for germination. Since K-selected species are climax species, they do not require light for germination; and, in fact, may be inhibited by sunlight during the germination process. Mesquite seedlings emerged and became established with 50% reduction in solar radiation, but survival was significantly reduced when radiant energy was reduced 75% or more (Scifres and others 1973). Fisher and others (1959) found that if grass cover is severely disturbed, chance of mesquite seedling establishment is substantially increased.

Germination of mesquite seeds under rangeland conditions varies from laboratory tests. Mesquite seeds are encased within very fiborous pods and are characterized by extremely hard seed coats. Mesquite seed germination is significantly enhanced after it passes through the digestive tract of an animal or is scarified by some other means. Ueckert and others (1979) found quite high emergence rates (17.4 - 47.0%) under field conditions, but survival rates were usually low (Ueckert and others 1979, Meyer and Bovey 1982). Most native plants have similar protective mechanisms that ensure survival of the population under unusual or adverse climatic conditions. Any population risks demise if all seeds germinate at the same time under similar environmental conditions. Seed polymorphism is important to the establishment and survival of seedlings and persistence of the population (Palmblad 1968a, 1968b, Harper and others 1970).

The seedling stage of all plants is the most vulnerable stage in the life cycle. Survival of seedlings depends upon the ability of the radicle to grow in wet soil which is very critical since the surface soil usually dries very rapidly. Seedlings are very susceptible to water stress because of the lack of development of anatomical and morphological features that conserve water.

It appears that seed germination and seedling emergence are among the most critical stages in plant succession. Seemingly, plant succession does not occur gradually along a gradient, especially in semiarid and arid climates, but rather, it occurs in spurts. Environmental conditions are not always conducive for seed germination and seedling establishment. Creosotebush (Larrea tridentata) that occupies much of the Southwest ranges and dominates many plant communities on the Jornada Experimental Range in southern New Mexico has not always enjoyed the geographic distribution that it now occupies. The first major influx of creosotebush into present day communities occurred in the early 1940's with above average rainfall (C. H. Herbel, personal communication). Several successive days of wet weather must accompany above average rainfall years for creosotebush to become established. Once it becomes established, however, few species can compete with it. Similar expansion of mesquite into communities that it now dominates has been observed following above average rainfall years in the 1960's.

PHENOLOGICAL DEVELOPMENT

Phenology (derived from Greek "phainein" which means "to show") is the study dealing with relations between climate and periodic biological phenomena. Phenological development is the progression of stages of growth during the annual cycle.

Plants spend the winter in some degree of resting. Much research has been devoted to resting phases of fruit trees and break of dormancy in the spring. Bud and tiller formation seem to occur during the spring and fall preceding the year in which they will be expressed. Environmental conditions during formation of buds and tillers directly affect biomass production the following year. Mesquite foliage is very dense in springs following a wet spring and fall the preceding year; whereas, less foliage is produced when the preceding spring and fall are dry. Budbreak in the spring is dependent on photo- and thermoperiods. Budbreak in indigenous plants and onset of dormancy are governed by their evolutionary history (Peacock and McMillan 1965). Goen and Dahl (1982) found that minimum air temperatures January through March and the number of days that the minimum fell below freezing dictated timing of budbreak of mesquite in west Texas. Regardless of temperatures, budbreak rarely occurs before the photoperiod exceeds 11.5 hours. Twig elongation in mesquite begins when the soil temperature reaches 65-70°F and continues for approximately 6 weeks (Haas and others 1973).

Apical dominance is an old concept regulating growth and development of all plants. Apical meristems are small, but they dictate the growth habit of all plants, both herbaceous and woody. Excellent reviews are provided by Romberger (1963) and Dahl and Hyder (1977). Theoretically, plants can live as long as the apical meristem is active. Once it is damaged or destroyed, the shoot dies. Many herbaceous and woody plants produce lateral buds that remain inactive until apical dominance is destroyed or they can produce adventitious buds.

Many of our difficult to control weedy perennials (herbaceous and woody plants) are sprouters; i.e., they sprout from lateral or adventitious buds following destruction of apical dominance. Silverleaf nightshade (Solanum elaeagnifolium) produces a massive root system which has given rise to debate whether most of the biomass is roots or rhyzomes. Once a shoot is destroyed, new shoots can arise from any portion of the root segment that is in a favorable soil environment (Stubblefield 1986). Mesquite responds similarly to loss of apical dominance. Mesquite sprouts from basal buds that arise from the buried cotyledonary node (Fisher and others 1946, Morey and Dahl, 1975) and dormant bud traces immediately below the bark (Haas and others 1973).

Growth of mesquite resprouts depends largely upon the time when apical dominance is removed. Plants with shoots that are damaged or mechanically destroyed (chemically or mechanically) during dormancy, sprout the following spring with great vigor. Often these sprouts will develop rapidly and flower the first growing season. If shoots are destroyed during the wet portion of the growing season when the root carbohydrate level is high, the plants will sprout rapidly, but usually the sprouts will not flower the same growing season. If, however, apical dominance is destroyed during a dry portion of the growing season or the root carbohydrate level is low, sprouting is suppressed for some time, perhaps as long as 3 to 5 years. Time of the year, phenological stage and environmental conditions at the time apical dominance is destroyed has more influence on sprouting and flowering of the resprouts than number of years post-destruction (Beck and others 1975). Flowering depends upon whether the sprouts produce long or short shoots (Dahl and Hyder 1977).

Native plants are uniquely adapted to their environment. Most produce more flowers than the plant can support if all matured into fruits and seeds. Annuals produce large numbers of seeds with tremendous variability. It has been suggested that one method of controlling annual plants is to mow them before seeds are produced. Species such as rescue grass (Bromus unioloides) and dandelions (Taraxacum officinale) will produce seeds at or below the surface of the soil. Many fruits are produced that abort before maturation (Stephenson 1981). Mesquite trees produce numerous flowers, but very few fruits per spike. Goen (1975) found that in the Rolling Plains of Texas some trees produced pods every year and some never produced pods. Production of pods varies from year to year. An old adage suggests that if mesquite trees produce many beans (pods), the year will be dry. Perhaps this is a survival mechanism for the population and there is some truth to the adage, although it is undocumented scientifically.

ROOTING HABITS

Most xerophytes and phreatophytes have the reputation of having deep taproots. However, it has been suggested that most of the xerophytes rely on a shallow lateral root system more than the deep taproot. Mesquite has a deep taproot 5 to 13 m (Fisher and others 1959) and even to depths of 58 m (Phillips 1963). It has an extensive lateral system with radii extending to 17 m (Fisher and others 1958, Cable 1977).

Recent evidence indicates that the most active laterals occur in the upper 75 cm of soil. Dahl and others (1971) and Dahl and Sosebee (unpublished data) have found that the most important environmental factor contributing to control of mesquite with foliar applied herbicide is soil temperature at depths between 30 and 60 cm. Transpiration was unaffected in trees with taproots severed at 75 cm if surface of the soil was wet, but it was significantly reduced when the upper 75 cm became dry (Thomas and Sosebee 1978). These results suggest that the deep taproot plays a significant role in water uptake only during extended droughts when surface moisture is lacking. Bedunah (1982) found annual forbs such as sunflower (Helianthus annus), and Russian thistle (Salsola kali) growing in and around pits created by grubbing (and removing) mesquite. Where pits were made by grubbing between the trees (with the trees left intact), no forbs grew, indicating competition from mesquite for soil water. Similar rooting behavior in mesquite has been observed by Jacoby and his coworkers (P. Jacoby, personal communication).

Although many plants have deep taproots and extensive lateral roots, they depend largely upon their shallow roots for most active absorption. In the dry southwestern and western parts of the U.S., dependence upon shallow roots is advantageous allowing plants to utilize the limited precipitation that infiltrates the soil. Reliance of xerophytes upon deep root systems is disadvantageous because of the depth to available water.

PHOTOSYNTHESIS AND TRANSPIRATION

Honey mesquite has high photosynthetic rates in semiarid and arid environments. Mooney and others (1977) found that at intercellular CO_2 concentration of 250 $\mu l \ l^{-1}$, the measured photosynthetic rates for mesquite in the Sonora Desert were over 30 mg $CO_2 \ dm^{-2} \ hr^{-1}$. Daily maximum CO_2 exchange rate of 28.6 mg $dm^{-2} \ hr^{-1}$ was reported by Dye and Hanson (1978) for semiarid Trans-Pecos Region of west Texas and CO_2 uptake rate of 32.9 mg $dm^{-2} \ hr^{-1}$ was measured by Meyer and others (1982) for Bryan, Texas. At the Texas Tech campus, Lubbock, Texas, with a ambient CO_2 concentration of a 350 $l \mu l^{-1}$, we measured a daily maximum photosynthetic rate of 33.54 mg $CO_2 \ dm^{-2} \ hr^{-1}$ in June. Following heavy precipitation the CO_2 exchange rate was even higher (41.2 mg $CO_2 \ dm^{-2} \ hr^{-1}$).

According to Larcher (1980), photosynthetic capacity ranged from 6 to 20 mg $CO_2 \ dm^{-2} \ hr^{-1}$ for desert shrubs and from 15 to 25 mg $CO_2 \ dm^{-2} \ hr^{-1}$ for sun leaves of winter deciduous trees. Therefore, photosynthetic capacity of mesquite exceeds the value for either the desert shrubs or the winter deciduous trees. It is similar to those of most C_3 crop plant species (20-45 mg $CO_2 \ dm^{-2} \ hr^{-1}$).

High photosynthesis of mesquite is probably related to its high leaf nitrogen content. In June, leaf Kjeldahl nitrogen contents can reach as high as 27 mg/g of the dry weight, which is equivalent to over 16% crude protein content. This value is close to the leaf nitrogen content of many desert winter annuals which are characterized by very high photosynthetic capacity (ranges from 28.15 to 103 mg $CO_2 \ dm^{-2} \ hr^{-1}$) (Werk and others 1983). The high leaf nitrogen content is associated with nitrogen fixation capability of honey mesquite. Several fold increase in soil nitrogen and organic matter content under mesquite canopy has been found by many people (Arthur and others 1972, Rundel and others 1982, Virginia and Jarrell 1982, Shearer and others 1983). The nodules were observed after a rain or in the soil layer where adequate soil moisture exists. This may partially explain the very high photosynthetic capacity of mesquite after the spring rainfall events.

Under favorable conditions, mesquite trees are not photosynthetically light saturated until a high irradiance level is reached. Hanson (1982) reported that light saturation point for mesquite was 1.78 mmol m^{-2} s^{-1} (400-700 nm radiation). In west Texas, this irradiance level is usually reached by 11:00 A.M. in June. In our field experiments, peak photosynthesis appeared between 11:00 A.M. - 2:00 P.M. after a heavy spring precipitation; and during this period, the quantum flux density was usually close to full sunlight (1.8-2.2 mmol m^{-2} s^{-1}). It is clear that honey mesquite requires high light intensity to achieve maximum photosynthetic rates. This is in contrast with many other C_3 plant species which are usually light saturated at 1/3 to 1/2 of full sunlight. The high light saturation requirement of honey mesquite resembles most C_4 plants and many desert species including ephemerals which have extremely high photosynthetic capacities. High light saturation point, high leaf nitrogen content and extensive rooting habit enable honey mesquite to successfully compete against many native species including some C_4 grass species such as bluegrama and buffalograss (Buchloe dactyloids). In hot and arid environments, photosynthetic rates of C_4 plants are generally greater than those of C_3 plants. However, this may not necessarily be correct in all situations. Although honey mesquite is a C_3 plant, its photosynthetic capacity is within the range of C_4 plants (30-80 mg CO_2 dm^{-2} hr^{-1}, Larcher 1980).

When soil water is not limited and relative humidity is high, photosynthesis of honey mesquite is mostly dependent upon light intensity. Daily maximum photosynthesis usually occurs at irradiance close to full sunlight. So does stomatal conductance. Photosynthesis and stomatal conductance increase almost linearly in the morning hours as irradiance increases. Then a depression occurs in the afternoon (fig. 1).

The diurnal curve exhibits a close coupling between photosynthesis and leaf conductance. This means that any increase in leaf conductance is associated with an increase in CO_2 uptake in the morning hours and suggests that the plant is photosynthesizing at least expense of transpirational water loss. In the meantime, the plant is able to maintain a relatively constant intercellular CO_2 concentration at about 250-270 µl l^{-1}.

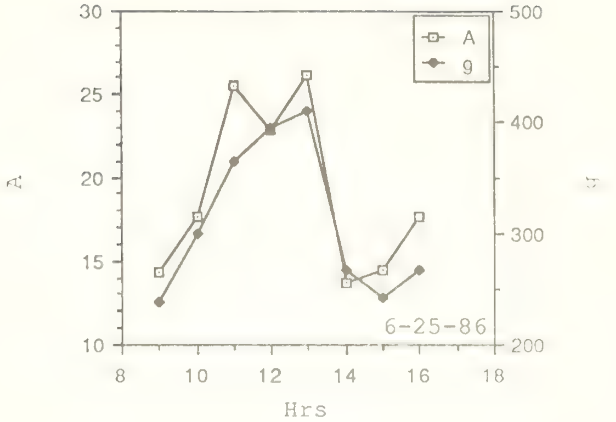

Figure 1--Diurnal photosynthesis (A, µmol CO_2 m^{-2} s^{-1}) and conductance (g, mmol m^{-2} s^{-1}) pattern during a wet period. Note the depression in A at 2:00 p.m. is accompanied by the decrease in g.

In a drought period, the morning photosynthesis of honey mesquite is not only dependent upon the irradiance levels, but also restricted by edaphic and atmospheric drought. Peak photosynthesis occurs several hours earlier than in the wet period. The magnitude of peak photosynthetic rates is also substantially reduced, and usually declines by half with a moderate soil water deficit and by 3-fold with a severe water stress. During wet periods, photosynthesis and leaf conductance are very responsive to irradiance levels; however, they become less responsive to irradiance in the drought period because water stress plays a major role in limiting CO_2 fixation. In drought periods, photosynthesis and leaf conductance of mesquite are influenced, to a large extent, by vapor pressure deficit (VPD) and soil water deficit. The stomata start to close at VPD exceeding about 30 mbars.

Depression in photosynthesis of mesquite under water stress conditions has been attributed mainly to stomatal closure (Dye and Hanson 1978, Hanson 1982), which was thought a result of decreased plant water potentials. In our experiments, it appeared that major limitation on photosynthesis of mesquite was not attributed to stomatal closure. In drought periods, stomatal conductance was much reduced, which caused the intercellular CO_2 concentration to become much lower than that in the wet period (average around 150-180 µl l^{-1}). However, with a similar internal CO_2 concentration, the trees growing on more mesic clay loam sites had photosynthetic rates 2-fold higher than the trees growing on xeric sandy loam sites. The midday depression in photosynthesis usually was not associated with lower internal CO_2 concentration, it was often higher instead. This indicates that under water stress conditions, the ability of mesophyll cells to fix CO_2 is reduced, which causes the internal CO_2 concentration to increase. Thus, instead of stomatal closure causing reduced photosynthesis, stomata of mesquite seem to respond to reduced photosynthesis and increased internal CO_2 concentration.

Our data further indicate that neither photosynthesis nor stomatal conductance is highly associated with xylem water potentials. In wet periods, the plants photosynthesized at high rates with stomata widely open, yet the xylem water potential was low. Likewise, during drought conditions, photosynthesis declined to a low level. So did stomatal conductance; but xylem water potential increased. There is nothing unique about xylem water potential regarding photosynthetic rate. Our data show that mesquite trees can maintain a positive carbon balance at xylem water potential of -40 bars, but sometimes net photosynthesis dropped to zero at xylem water potential of -34 bars. In midsummer, mesquite growing on the more mesic sites achieved greater photosynthetic rates than the trees on the xeric sites; but, we found no difference in xylem water potential between the two sites. Lack of correlation between photosynthesis and xylem water potential suggests that xylem water potential may be of minor importance in affecting photosynthesis of mesquite.

Seasonal change in photosynthetic capacity of mesquite is tightly correlated with soil water availability. For two consecutive years, we found a significant linear relationship (r=0.89; p=0.001) between daily maximum photosynthesis and soil water content at the 30 to 60 cm depth on a fine sandy loam (fig. 2).

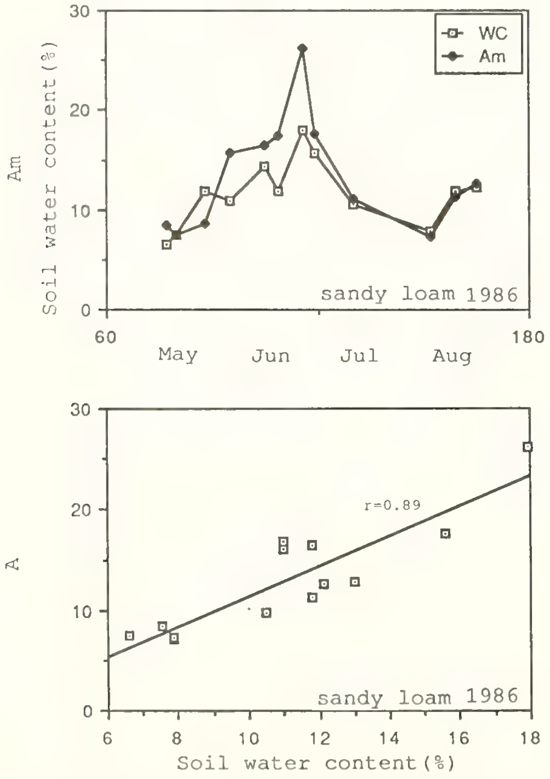

Figure 2--Upper: Seasonal change of daily maximum photosynthesis (Am, µmol m^{-2} s^{-1}) as affected by soil water content (w/w). Lower: Relationship between Am and soil water content. P=0.001.

The average photosynthetic rates were also related to soil moisture levels. This provided evidence that the major site for the plant to "sense" water stress is the root system, as recently suggested by Turner (1986).

Although honey mesquite is considered a phreatophyte, its photosynthetic capacity is susceptible to soil water availability. This further confirms that honey mesquite in west Texas is not a true phreatophyte, but a falcutative phreatophyte (Thomas and Sosebee 1978). It primarily depends on moisture held in the upper soil horizon for its physiological requirement. Whereas, the taproot is not functional until water in the surface soil is depleted.

Wendt and others (1967) found that transpiration and growth of mesquite seedlings in a greenhouse were affected by soil temperature. Our field data suggest that photosynthesis of honey mesquite is also influenced by soil temperature when soil moisture is not limiting. On a clay loam site near a playa where seasonal changes in soil moisture were minimal, photosynthetic capacity of mesquite during the spring rainy season mainly responded to soil temperature regime and soil aerobic conditions. The greatest photosynthetic rates occurred when the soil temperature at 45 cm was relatively high (23-24°C) and soil moisture content was about 70-80% of field capacity. However, when soil was saturated after a heavy rainfall and soil temperatures dropped to 21°C, photosynthesis declined. This response of photosynthesis to soil temperature was observed for 2 years. Low soil temperature and anaerobic conditions apparently colimit photosynthesis. Whether the effect is direct or indirect needs further investigation.

The temperature optima for photosynthesis of mesquite ranges from 27°C to 31°C, which fall in the upper range of optimum temperature for C_3 plants (20-30°C). Similar data were presented by Dye and Hanson (1978), Hanson (1982), and Meyer and others (1982). This temperature optima for photosynthesis is very similar to the optimum soil temperature (29°C) for root function. However, there is a seasonal shift in optimum temperature for honey mesquite. In late October and early November, the daily peak photosynthesis occurred at air temperatures from 14 to 18°C. When quantum flux density approached 1.2 mmol m^{-2} s^{-1} and air temperature further increased to over 20°C, photosynthesis declined. Available soil water content was not limited in this period. This change in temperature optima may reflect temperature acclimation of mesquite when the plant is subjected to a low temperature environment.

The ability to acclimate to a low temperature environment has ecological significance. It can extend the growing season for honey mesquite and enhance its competence. Most C_4 plants cannot tolerate low temperatures and are not active photosynthetically when the temperature drops to about 10°C. In contrast, honey mesquite can achieve peak photosynthesis at 14°C after occurrence of the first frost. In west Texas, most C_4

species start growth a month later than mesquite and stop photosynthesizing much earlier than mesquite. This makes the growing season for mesquite much longer than its C_4 counterparts and enables the plant to more efficiently use available resources.

Honey mesquite is also capable of acclimating to high temperature regimes. Thermal stability of the plant increases as the season progresses. On hot afternoons, zero CO_2 exchange is observed in the native habitat because of inhibition caused by high leaf temperatures and water stress. Ability of the plants to deal with high temperature stress is associated with the length of time the tree is exposed to a high temperature environment. In mid June, zero net photosynthesis occurred at a leaf temperature of 37°C in the light green leaf stage while positive CO_2 exchange rate was obtained at 39°C in the dark green leaves. In late July, the plants maintained a positive net assimilation rate at a leaf temperature of 42.5°C.

A linear relationship between photosynthesis and leaf conductance existed in mesquite trees (P = 0.001, r = 0.7 to 0.84, n = 130) across different environmental conditions (fig. 3).

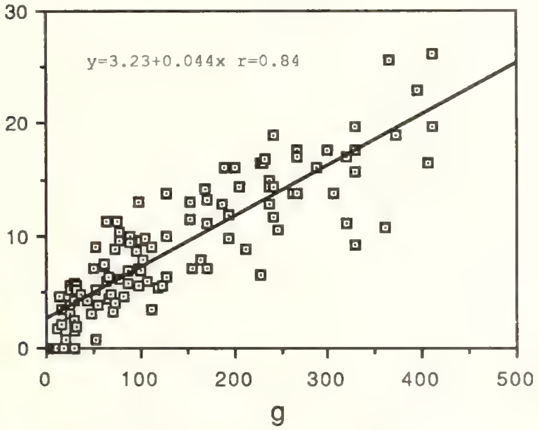

Figure 3--Relationship between photosynthesis (A, μmol m^{-2} s^{-1}) and leaf conductance (g, mmol m^{-2} s^{-1}) in honey mesquite in Lubbock, Texas (n=130, P=0.0001).

This relation has revealed that the plant can achieve maximum water use efficiency (WUE) in its native habitat. Mesquite is not wasteful in terms of water cost per unit carbon gained. Even when soil water is most available, the plant does not use water extravagantly as many have thought. In wet periods, honey mesquite can have a water use efficiency of 9.7 mg CO_2/g H_2O, which is similar to that of some C_4 plants (Caldwell and others 1978). This high WUE is attributed to high photosynthetic rates when soil water is adequate. High WUE is also due to stomatal regulation on transpirational water loss. When the environment favors plant growth as in June, stomata are open and transpirational water loss is high, but the plants fix as much CO_2 as possible. When the high VPD promotes transpiration, as in July, photosynthesis is inhibited. As a consequence, stomata are closed, so extra water loss can be prevented. Therefore, seasonal WUE of honey mesquite tends to approach maximum. Diurnal WUE remains relatively constant. This kind of stomatal behavior is optimal in a semiarid environment; it allows the plant to better adapt to the water limited habitat. It provides another explanation for the expansion of honey mesquite into the semiarid Texas rangeland.

PHOTORESPIRATION

Mooney and others (1977) measured photosynthetic capacity as high as 62 mg dm^{-2} hr^{-1} in honey mesquite under unlimited light, nutrient and water conditions at intercellular CO_2 pressure of 250 μbar. However, nobody has measured such a high photosynthetic rate in the field because the field condition is far from optimum. In a hot summer, net photosynthesis of mesquite is substantially reduced. Water stress and high leaf temperatures are believed to cause this sharp decline in net photosynthesis since they accelerate photorespiratory CO_2 evolution. In normal conditions, most C_3 plants have photorespiration rates of 30 to 40% of net photosynthesis (Bjorkman 1966).

Photorespiration rate is determined as the difference between gross photosynthesis and net photosynthesis. Measured photorespiration in C_3 plants is sensitive to oxygen concentration and is virtually eliminated in an atmosphere of 2% oxygen at moderate temperatures (D'Aoust and Cavin 1972, 1974). Therefore, CO_2 exchange rate at 2% O_2 is an estimate of gross photosynthesis and net photosynthesis is the CO_2 exchange rate at 21% O_2. By using the above method, we measured photorespiration rate in mesquite under field conditions.

In honey mesquite, a considerable amount of carbon (30% of net photosynthesis) is channelled into photorespiratory CO_2 oxidation cycle (PCO cycle). In late May, 1985 -- a dry period -- the daily maximum photosynthetic rate was 12.47 mg CO_2 dm^{-2} hr^{-1}, which approximates 1/3 of the rates obtained in the rainy period. Net photosynthesis reached a plateau at noon when the irradiance exceeded the light saturation requirement for mesquite. It then declined linearly as air temperature increased from 31.3 to 37.5°C. By 3:00 P.M. it was reduced to zero. In the meantime, photorespiration increased and reached a maximum. By 3:00 P.M., the rate of CO_2 uptake was equal to the rate of CO_2 evolution; i.e., CO_2 evolved through the photorespiratory CO_2 oxidation cycle was refixed in the photosynthetic CO_2 reduction cycle (fig. 4).

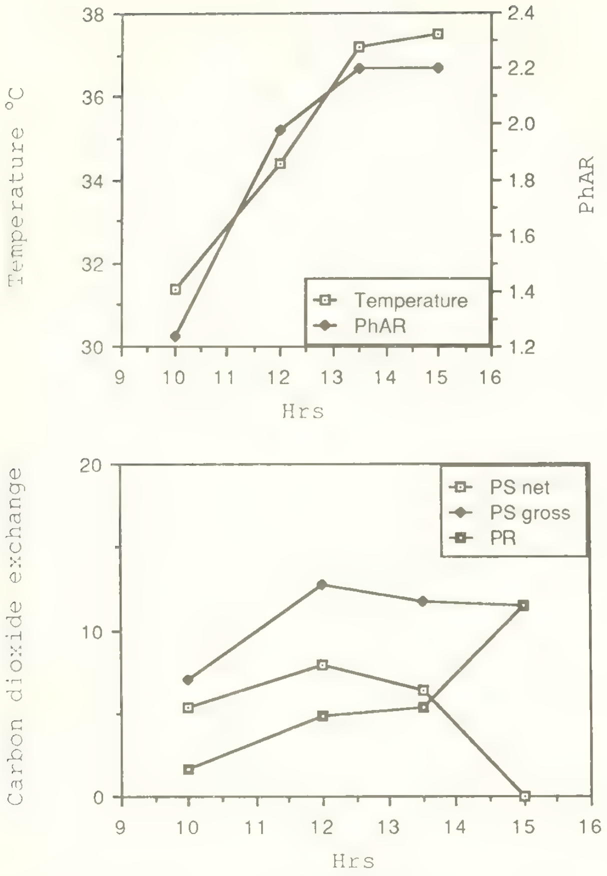

Figure 4--Upper: diurnal change in air temperature and photosynthetically active radiation (PhAR mmol m^{-2} s^{-1}). Lower: diurnal change in net and gross photosynthesis (μmol CO_2 m^{-2} s^{-1}) and photorespiration (μmol CO_2 m^{-2} s^{-1}) as affected by air temperature.

Canvin (1982) has shown that at a temperature of 29.2°C, light intensity of 0.4 mmol m^{-2} s^{-1}, and external CO_2 pressure of 340 μbar, photorespiration rate of sunflower (Helianthus annuus L. var. CM90RR) was 45% of net photosynthesis (14.22 mg CO_2 dm^{-2} hr^{-1}). In mesquite, at leaf chamber temperature of 31.3°C, external CO_2 pressure of 320 μbar and photon flux density of 1.25 mmol m^{-2} s^{-1}, the photorespiration rate was 2.7 mg CO^2 dm^{-2} hr^{-1}, which was 30% of net photosynthesis. This photorespiration rate is very close to the range (3 to 10 mg dm^{-2} hr^{-1}) reported by Zelitch (1971).

The photorespiration rate of mesquite is very responsive to temperature increase. At high temperatures, CO_2 solubility is more affected than that of O_2, resulting in increased O_2/CO_2 ratio which inhibits rate of carboxylase reaction and enhances rate of oxygenase reaction. This detrimental effect of high temperature on net photosynthesis of mesquite is more pronounced when soil water is limited, because insufficient latent heat transfer tends to raise leaf temperature even higher. Although mesquite has been described as productive in semiarid areas, it is doubtful that it can maintain high productivity in the summer months. Our data suggest that in midsummer honey mesquite only actively photosynthesizes in the morning hours, and becomes inactive in the afternoon.

The reduction in net photosynthesis has been attributed to decreased xylem water potential which triggers stomatal closure, hence increased resistance to CO_2 diffusion (Dye and Hanson 1978). However, correlation between stomatal conductance and xylem water potential was not significant, and the conductance was more closely related to soil water status. Fig. 5 shows that when photosynthesis was high in the morning, xylem water potential declined to a low level, whereas zero net photosynthesis occurred when xylem water potential was higher.

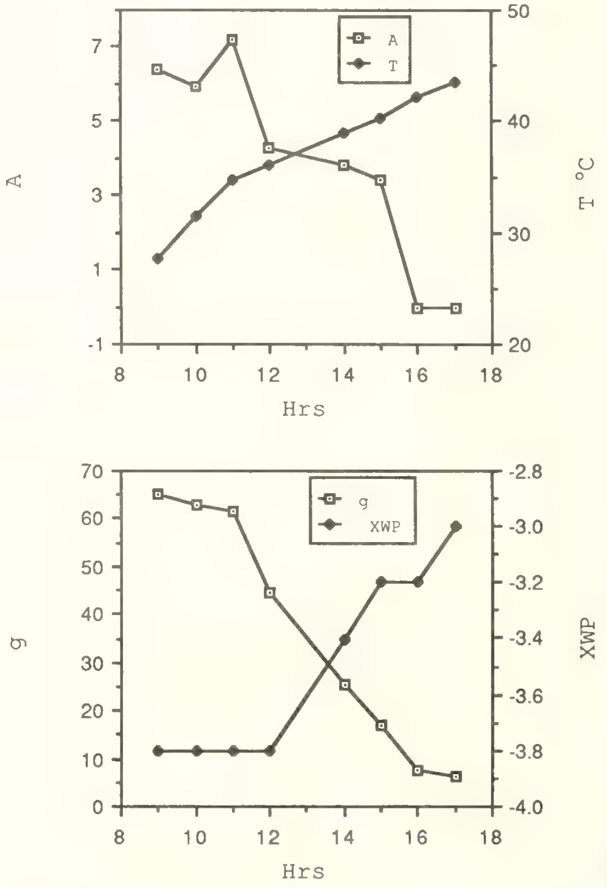

Figure 5--Upper: net photosynthesis (A, μmol m^{-2} s^{-1}) as affected by leaf temperature (T, °C). Lower: diurnal changes in leaf conductance (g, mmol m^{-2} s^{-1}) and xylem water potential (XWP, Mpa) under a severe water stress conditions.

Increased resistance to CO_2 diffusion was unlikely to be the major limitation on photosynthesis because the photosynthetic capacity is saturated at low intercellular CO_2 concentrations. It seems that the major influence of stomatal closure on photosynthesis of mesquite is through increasing leaf temperature which enhances the CO_2 compensation point and the O_2 inhibition of photosynthesis rather than through increasing resistance to CO_2 diffusion. As Fig. 5 shows, photosynthesis decreased with increasing leaf temperature.

Energetically, photorespiration is a wasteful process because ATP cost of the CO_2 assimilation is increased. In the hot dry summer, this may benefit the plant since extra heat can be dissipated through this process. According to the biochemical pathway, production of 1 mole CO_2 from PCO cycle consumes twice as much ATP and NADPH as its refixation in photosynthesis. It can also allow the plant avoidance of photo-oxidative damage to photosynthetic apparatus, such as chlorophyll bleaching.

CARBOHYDRATE TRANSLOCATION

It has been well known that food movement in the plant is from the site of photosynthesis to the site of growth or storage. Photoassimilate translocation follows the concentration gradient that becomes established between source and sink. This gradient is maintained osmotically by regulated loading of solutes into the sieve element companion cell symplast in source regions and regulated unloading in sink regions (Gifford and others 1984). The greater the utilization at a sink, the steeper the gradient. The gradient becomes greater when photosynthesis is more active. Therefore, photosynthesis, phenological development and environmental factors are the major considerations in the study of carbohydrate translocation in honey mesquite.

Unfortunately, most studies in the past have only focused on the relationship between sugar translocation and environmental factors, and overlooked the food producing process -- photosynthesis. The major emphasis has been devoted to sugar translocation to the roots, since this process is involved in herbicidal control of the plant. Carbohydrate translocation in the plant is driven by carbohydrate concentration gradient between the source and sink. Thus, a better understanding in carbohydrate translocation relies on our knowledge in the changing relations between source and sink as well as interactions among various sinks and source.

Root TNC trends of mesquite have been well established (Wilson and others 1975, Fick and Sosebee 1981, Seipp 1982, Dahl and Sosebee 1984). After reproductive growth is complete in the fall, more photoassimilate is available for downward translocation; in addition, the initiation and development of new crown buds and root growth also call for food importation, so downward carbohydrate translocation is operating at its maximum rate. A peak root TNC is reached at the end of the growing season. Root TNC level in the early spring is somewhat reduced because of consumption by root respiration over winter. Immediately after budbreak, root TNC declines rather rapidly and drops to a minimum in May, about 42 days after budburst. This root TNC depletion is primarily caused by rapid root growth in the spring. In the subsequent period of about 20 days, root TNC is replenished and reaches a peak in mid June, which is often accompanied by flower abortion and initiation of small pods. This peak is followed by another sharp decline, and a minimum TNC occurs in early July; approximately 11 days is required for this discharge process. Pod elongation usually occurs during this period and is considered as a strong sink for photosynthates. Before summer drought starts, there is a second recharge period, which usually terminates about 84 days post budbreak. The third recharge event occurs during August through September and follows the major reproductive growth (fig. 6).

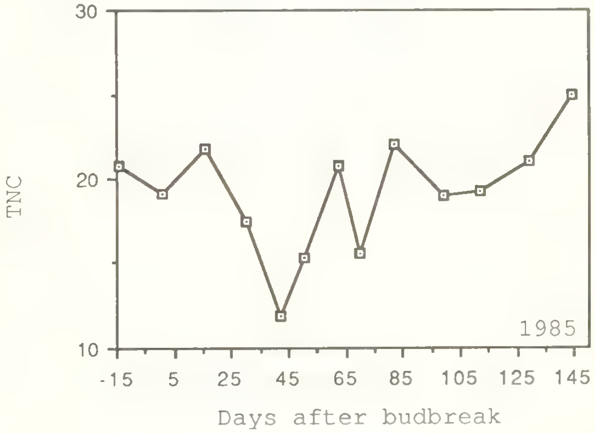

Figure 6--Root total nonstructural carbohydrate (TNC, mg/100mg) trend in honey mesquite growing on a sandy loam site in Lubbock, Texas.

Carbohydrate translocation to the roots is subjected to the effect of numerous physiological and environmental factors. The amount of carbohydrate being allocated to the roots depends on the development of other sink organs. Trees with a large proportion of flowers and pods would have lower root TNC concentration than trees with a smaller proportion of flowers and pods. Higher soil temperatures usually promote carbohydrate translocation to the roots, providing soil moisture is not limiting. In the spring, when soil has adequate moisture, soil temperature affects downward TNC translocation by stimulating rapid root growth, thus rapid TNC consumption. At low temperatures, the consumption of sugar is slowed due to reduced metabolic activity of roots and accumulation of TNC in the roots would tend to diminish the carbohydrate concentration gradient between the source and sink, and TNC translocation to the roots would be deferred. Furthermore, there is some evidence that low soil temperatures affect photosynthetic capacity of mesquite, which brings about a reduced source strength. Therefore, at low soil temperature both sink (root) strength and source strength would be reduced. We have found that on a sandy loam site where soil temperature is higher than on a clay loam site in the spring, carbohydrate translocation to the roots is faster.

Soil moisture affects downward carbohydrate translocation through direct or indirect influence on plant physiological processes. The greatest influence is reduced photosynthesis under water stress conditions. When mesquite is severely water stressed, downward sugar translocation is slowed to a minimum or even stopped. Root activity is also affected by soil water deficit; therefore there is a diminishing requirement for influx of sugar. When the loading of sucrose at source sites becomes sluggish due to decreased assimilation rates and unloading at sink sites is blocked through reduced root growth, the driving force for the downward TNC translocation will no longer exist.

In a wet year, root TNC recharge would occur three times, whereas in a dry year, the roots can only replenish their reserve twice (Seipp 1982). The active downward carbohydrate translocation is a reflection of the overall high physiological activity of the plant. Seipp (1982) found that rapid increase of root TNC in early June, 1980, was related to higher than average soil water content in the rooting zone just prior to that period. Our results have shown that downward carbohydrate translocation was not affected by -1.5 MPa soil water potential.

The optimum condition for downward carbohydrate translocation has to meet both moisture and temperature requirements, but too much water in the profile tends to lower soil temperature. On a heavy soil, the greatest root TNC recharge occurs not during a period of saturated soil moisture condition, but during a period of higher soil temperature and relatively good moisture conditions. This seems logical because root growth is less sensitive to a moderate water stress than shoot growth (Bradford and Hsiao 1982). When a stress level is just enough to inhibit leaf expansion and reproductive growth, root activity may not be affected and can continue to serve as a strong sink for photosynthates. It has been generally agreed that the plant growing on a less mesic site would have an increased ratio of root to shoot biomass. Some controversies have been evoked on the effect of water stress on carbon translocation in the plants. Fick (1978) found that soil moisture at the 15-cm depth was negatively correlated with root TNC of mesquite ($r = 0.96$) during the phenological stages of green spikes and green pods. Wardlaw (1967) suggested that the velocity of translocation was little affected by water stress. As far as drought effect on carbohydrate translocation is concerned, it is necessary to define the stress level and the stress effect on related physiological activity of the plant. The question to be addressed is not whether water stress affects carbohydrate translocation, but how translocation is affected by different levels of water stress. Dahl and others (1971) and Sosebee and others (1973) found that water deficit in the surface soil was negatively correlated with root kill of mesquite by herbicide application. This does not mean that drier the soil, greater the downward sugar translocation. Dahl and Sosebee (1984) pointed out that dry springs usually will not stress mesquite unduly, since deep moisture is generally available.

TNC concentrations in buds, stems and twigs are usually lower than those of roots and trunk (Fick and Sosebee 1980, Seipp 1982), suggesting the roots and trunk are more important storage organs. Since buds, stems and twigs are actively growing tissues, their reserves are likely to be consumed rather quickly, especially in twigs which have the lowest TNC concentration in the season. At the time of budbreak, TNC concentration in all plant parts decreases. Because stems and twigs are proximal to the buds, they are assumed to provide more carbon and energy to the emerging buds than the roots and trunks. Seipp (1982) suggested that the primary energy source for budburst of honey mesquite is derived from aboveground storage organs such as buds, stems, and twigs.

Since root TNC is mainly consumed by root growth, its concentration usually undergoes great fluctuation in the spring when the roots are rapidly growing. Rate of root TNC recharge is considerably higher than that of aboveground plant parts (Seipp 1982). It appears that the root system is the strongest sink in the downward carbon flow. This may explain why the root TNC recharge rate is greater for the trees with fewer flowers and pods and lower for the trees with many flowers and pods. Competition for photoassimilates between root growth and reproductive growth is often in favor of the latter. Therefore, pod elongation and floral development have marked influence on root TNC levels. Wilson and others (1974, 1975) suggested that maturing pods are primarily responsible for a low root TNC level during July. It has also been shown that in mesquite, carbohydrate translocation to the roots and stems is more active following the termination of reproductive stage and the recharge in the storage organ is considerably slowed during flowering. Wilson and others (1975) revealed that root TNC recharge was influenced by relative proportion of reproductive organs and the rate of recharge would be slow in the trees with young and blooming spikes and fast in those with mature pods.

Fick and Sosebee (1981) found that between development of green flower spikes and small pods during June, TNC levels in stems and twigs increased substantially while pod TNC remained low.

Our data have shown a similar trend with root TNC. This rapid translocation coincides with the great photosynthetic activity of the plant in this period. During the recharge period, increase in root TNC is positively correlated with rate of photosynthesis on a sandy loam site ($r = 0.81$, $P = 0.01$). When the immature green pods start pod filling beginning in late July (fig. 7), the pod TNC level increased at a much higher rate than the increase in stem and basal buds (Fick and Sosebee 1981). Since pod filling is a critical stage in plant regeneration, the trees have to sacrifice other plant parts in order to supply the pods with sufficient quantity of assimilates. Top priority for the plant at this time is maturation of seed pods and the importance of downward carbohydrate translocation becomes secondary. After pods mature, which usually occurs in mid August, there is a significant TNC recharge in roots and stems for storage; whereas TNC declines in basal buds, which is associated with a flush of new buds.

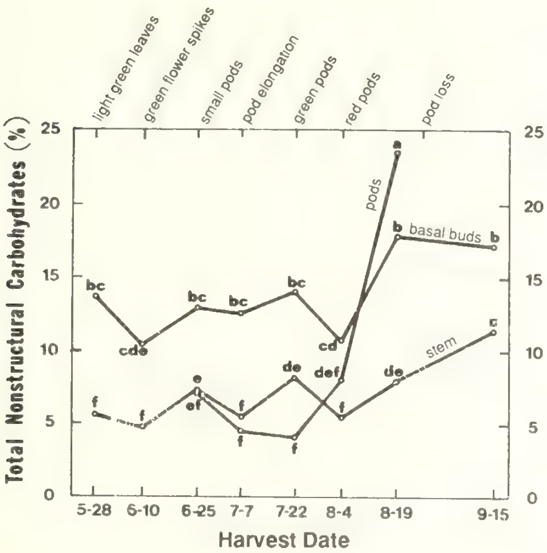

Figure 7--Total nonstructural carbohydrates in the basal buds, stems, and pods of honey mesquite trees harvested between May 28 and September 15, 1975. Phenological development is also indicated. TNC levels not followed by a similar letter differ significantly at the 5% level (Fick and Sosebee 1981).

Leaf TNC trend has received little attention in carbon translocation studies in honey mesquite. The leaf is the source of assimilate and leaf TNC level subjected to diurnal fluctuations, depending on rates of photosynthesis and translocation. Only limited information on leaf TNC is available at present. A moderate leaf TNC content occurred in mid June when the plants were actively photosynthesizing. This TNC level may reflect that higher rate of photosynthetic CO_2 fixation is balanced by an active outward photosynthate translocation. Leaf TNC increased to a higher level in July when the plants were suffering water stress. The accumulation to TNC in leaves may be a result of reduced expansion growth and is probably related to osmotical adjustment of the plant since sugar is the major component of osmotica. It has been found that osmotical adjustment in honey mesquite could reach as high as 2.4 Mpa (Nilsen and others 1983), which is equivalent to a water potential of 1 molal glucose solution. This high TNC content has a great feedback inhibition on photosynthesis as indicated by much reduced photosynthetic rates in July. The feedback inhibition may involve a decreased concentration of metabolically available phosphate. The leaf TNC decreased in August, indicating that TNC was remobilized to mature pods. Even lower leaf TNC levels in October are probably due to rapid carbon translocation to roots and stems and symbolizes leaf senescence. More detailed information on leaf TNC content is needed in studying photosynthetic performance and translocation pattern of honey mesquite.

GROWTH REGULATORS

Much research has been conducted on hormones and growth regulators, but limited work has been done relative to honey mesquite. It was found that effectiveness of herbicide application to control mesquite was enhanced by addition of niacin, thiamine, biotin, or pyridoxin (Sosebee 1974). It was concluded that these vitamins stimulated root growth and improved effectiveness of herbicide. Brumley (1974) found that mesquite seedlings grown in soil temperature of 27°C had significantly higher niacin concentration in the roots than either those grown at 21°C or those grown at 32°C, indicating that 27°C is the optimum soil temperature for root growth of mesquite. The results have also revealed that low or high soil temperatures affect niacin translocation from the shoots to the roots. This is consistent with the carbohydrate translocation trend as influenced by soil temperature regimes. Since niacin is an electron acceptor in the respiration process, it is reasonable that its translocation follows the same pattern as carbohydrate translocation. On a heavy clay loam soil where lower than optimum soil temperature prevails in the spring, the highest photosynthetic rates were obtained at a soil temperature of 27°C. It is not surprising that transpiration and growth of mesquite reached maximum at the same temperature range. Higher niacin concentration stimulated shoot growth more than root growth at 27°C soil temperature regime than at either 21°C or 32°C temperatures. Therefore, the shoot/root ratio was higher in the trees with a higher niacin concentration as suggested by Brumley (1974). He also found that nodulated mesquite trees exhibited a tendency toward decreased shoot/root ratio and increased niacin concentration in the roots. When nodulated, more niacin is required in enhanced root respiration.

Thiamine is another important vitamin involved in carbon metabolism. Brumley (1978) found that as mesquite leaves became mature there was a steady increase in thiamine concentration. In the white flower stage, the major peak of thiamine concentration occurred in twigs and phloem, indicating a high metabolic activity in twig and flower and rapid translocation of thiamine throughout the plant. In the flower abortion stage, there were peaks in thiamine concentration in the phloem and roots, which coincided with root TNC recharge. During pod maturation, peaks in thiamine concentration occurred in all plant parts, suggesting an intensive biochemical synthesis and growth in both above- and belowground plant parts.

Thiamin and niacin concentrations were drastically reduced when soil water deficit occurred and thiamin concentration was less affected by soil temperature below 27°C (Brumley 1978). Thiamin and niacin concentrations were more associated with phenological development than edaphic factors. It appears that physiological activities of mesquite are regulated by the concentration changes in these vitamins, which are coupled with development stages and affected by the environmental parameters.

Ethylene is a natural product of plant metabolism, which can exert various regulatory control over plant growth and development and is recognized as a plant hormone. Parsons and Sosebee (1974) studied the effect of ethrel (an ethylene releasing compound) on the phenological development in honey mesquite. Their results revealed that bud potential of mesquite was not regulated by ethrel application. The bud number and development of the leaves following budbreak exhibited no difference between control plants and those treated with ethrel. However, the flower index increased following applying ethrel. The same stimulating effect on flowering was found in pineapples by Burg and Burg (1966).

Almost all physiological processes of honey mesquite are affected by soil conditions. For example, photosynthesis and conductance are highly correlated with soil moisture. Rate of transpiration is influenced by soil temperature (Wendt and others 1967). Mesquite cannot survive flooding and its growth is eliminated along the flood plains (Marks 1950, Busby 1970). Downward translocation of vitamins and carbohvdrates is affected by both soil moisture and soil temperature. All of these seem to imply an existence of a communication between root and shoot. This communication must be mediated by a hormone produced in the roots. This hormone is probably cytokinins. Since cytokinins are synthesized primarily in root meristems, any factors affecting root meristematic activity may have profound effects on cytokinin synthesis. Cytokinins are known to promote protein synthesis and photosynthesis and stimulate stomatal opening (Meidner 1967, Jewer and Incoll 1980). When plants were water stressed, their roots contained much less cytokinin activity than the control plants and the cytokinin concentration in both roots and leaves were reduced by half (Itai and Vaadra 1968, 1971). Reduction in photosynthesis and leaf conductance of mesquite may be caused by a reduced cytokinin synthesis and transport from the roots to the shoots or as a result of decreased ratio between cytokinins and abscisic acid (ABA) - the stress hormone (Schulze 1986). It seems that response of honey mesquite to water stress or low temperature stress is primarily sensed in the soil by the root system. Root-shoot communication is involved in the stress response of the plant, which is probably mediated by hormones.

CONCLUSIONS

Plant ecophysiology is an exciting field. It is not a new concept, but it has received more emphasis during the last 30 years than ever before. Physiological studies help explain ecological relationships within natural ecosystems. Honey mesquite was selected as a case study for this presentation because of the amount of research that has been conducted on it and because of the familiarity of the authors with this species. Intentions of the data presented are not to suggest that all species respond physiologically to the environment the same as honey mesquite. But, it is suggested that plants growing in their native habitats are very well adapted and often respond to the environment differently than we perceive their response.

Seed polymorphism has evolved through natural selection to insure germination and seedling survival. Since the seedling stage of most, if not all, plants is the most vulnerable, it is important that seeds "land" in safe sites where their requirements for germination and subsequent seedling establishment can be met. Conditions conducive for germination and establishment do not occur every year. Therefore, germination of seeds and establishment of seedlings occurs at irregular and, perhaps infrequent, intervals which gives rise to erratic changes in succession and revegetation of deteriorated communities, particularly in the West and Southwest.

Basic physiological and morphological studies reveal that endemic plants are well-adapted to their habitats. Photosynthesis and transpiration are well tuned to take advantage of and to cope with prevailing environmental conditions. Generally, consumptive water use by endemic species is not as great as purported, except for phreatophytes. Photosynthesis also varies from laboratory and greenhouse studies. Plants adapted to high temperature regimes have high thermal stability and are very tolerant of the high temperatures.

More ecological studies should be approached from an ecophysiological viewpoint. Close attention should be paid to phenological development and to the different stages of growth. Environmental conditions should be evaluated in detail. Basic physiological measurements need to be repeated through time to ascertain variations associated with changes in environment and phenological development. A thorough understanding of the ecophysiological processes of both native and introduced plants will help improve management of these species and the communities they inhabit.

REFERENCES

Arthur, R. T. and J. O. Klemmedson. 1973. Effect of mesquite on physical and chemical properties of the soil. J. Range Manage. 26:27-29.

Barbour, M. G., J. H. Burk, and W. D. Pitts. 1987. Terrestrial plant ecology. (Second edition). The Benjamin/Cummings Pub. Co., Inc., Menlow Park, California, 634 p.

Beck, D. L., R. E. Sosebee, and E. B. Herndon. 1975. Chemical control of mesquite regrowth of different ages. J. Range Manage. 28:408-410.

Bedunah, D. J. 1982. Influence of some vegetation manipulation practices on the bio-hydrological state of a depleted deep hardland range site. Ph.D. Dissertation. Texas Tech University, Lubbock. 188 p.

Bjorkman, O. 1966. The effect of oxygen concentration of photosynthesis in higher plants. Physiol. Plant. 19:618-33.

Bradford, K. J., and T. C. Hsiao. 1982. Physiological responses to moderate water stress, p. 264-324. *In*, Lange and others (ed.) Physiological Plant Ecology II. Water relations and carbon assimilation. Berlin/Heidelberg/New York: Springer Verlag Encycl. Plant Physiol., Vol. 12B.

Briske, D. D., and A. M. Wilson. 1977. Temperature effects on adventitious root development in blue grama seedlings. J. Range Manage. 30:276-280.

Briske, D. D., and A. M. Wilson. 1978. Moisture and temperature requirements for adventitious root development in blue grama seedlings. J. Range Manage. 31:174-178.

Briske, D. D., and A. M. Wilson. 1980. Drought effects on adventitious root development in blue grama seedlings. J. Range Manage. 33:323-327.

Brumley, C. S., and R. E. Sosebee. 1978. Influence of soil temperature on niacin and thiamin in honey mesquite. Plant and Soil. 50:13-23.

Burg, S. P., and E. A. Burg. 1966. Auxin-induced ethylene formation: its relation to flowering in the pineapple. Science 152:1269.

Busby, F. E. 1970. Distribution and spread of phreatophytes on the Brazos River flood plain. M. S. Thesis, Texas Tech University, Lubbock. P. 45

Cable, D. R. 1977. Seasonal use of soil water by mature velvet mesquite. J. Range Manage. 30:4-11.

Caldwell, M. M., R. S. White, R. T. Moore, and L. B. Camp. 1977. Carbon balance, productivity, and water use of cold-water desert shrub communities dominated by C_3 and C_4 species. Oecologia 29:275-300.

Canvin, D. T. 1982. Photorespiration comparison between C_3 and C_4 plants, p. 369-391. *In* M. Gibbs and E. Latzko (Eds.) Photosynthesis II. Berlin/Heildelberg/New York: Springer Verlag Encycl. Plant Physiol., Vol. 6.

Clausen, J., D. D. Keck, and W. M. Heisey. 1940. Experimental studies on the nature of species. I. The effect of varied environments on western North American plants. Carnegie Institution of Washington Pub. 520. Carnegie Institution of Washington, Washington, D.C. 452 p.

Dahl, B. E., R. B. Wadley, M. R. George, J. L. Talbot. 1971. Influence of site on mesquite mortality. J. Range Manage. 24:210-215.

Dahl, B. E., and D. N. Hyder. 1977. Development morphology and management implications, p. 257-290. *In* R. E. Sosebee (ed.), Rangeland Plant Physiology Range Science Series. No. 4. Society for Range Management. Denver, Colorado.

Dahl, B. E., and R. E. Sosebee. 1984. Timing- The key to herbicidal control of mesquite, Management Notes, Texas Tech University, Range and Wildlife Management.

Davies, M. S., and R. W. Snaydon. 1973a. Physiological differences among populations of *Anthoxanthum odoratum* L. collected from the Park Grass Experiment, Rothamsted, I. Response to calcium. J. App. Ecol. 10:33-45.

Davies, M. S., and R. W. Snaydon. 1973b. Physiological differences among populations of *Anthoxanthum odoratum* L. collected from the Park Grass Experiment, Rothamsted, II. Response to aluminum. J. App, Ecol. 10:47-55.

Davies, M. S., and R. W. Snaydon. 1974. Physiological differences among populations of *Anthoxanthum odoratum* L. collected from the Park Grass Experiment, Rothamsted, III. Response to phosphate. J. App. Ecol. 11:699-708.

Dye, A. J., and J. D. Hanson. 1978. Photosynthetic rates of honey mesquite in semiarid grasslands, p. 411-413. *In* D. Hyder (ed.) First Internat. Rangeland Congress, Proc. Society for Range Management, Denver, Colo.

Fick, W. H., and R. E. Sosebee. 1981. Translocation and storage of ^{14}C-labeled total nonstructural carbohydrates in honey mesquite. J. Range Manage. 34:205-208.

Fisher, C. E., J. L. Fultz, and H. Hopp. 1946. Factors affecting action of oils and water-soluble chemicals in mesquite eradication. Ecol. Monogr. 16:109-126.

Fisher, C. E., C. H. Meadors, R. Behens, E. D. Robison, P. T. Marion, and H. L. Morten. 1959. Control of mesquite on grazing lands. Texas Ag. Exp. Sta. Bull. 935. College Station, Texas. 24 p.

Frasier, G. W., J. R. Cox, and D. A. Woolhiser. 1985. Emergence and survival response of seven grasses for six wet-dry sequences. J. Range Manage. 38:372-377.

Fulbright, T. E., A. M. Wilson, and E. F. Redente. 1985. Green needlegrass and blue grama seedling growth in controlled environments. J. Range Manage. 38:410-414.

Gifford, R. M., J. H. Thorne, W. D. Hitz, and R. T. Giaguinta. 1984. Crop productivity and photosimulate partitioning. Science 225:801-808.

Goen, J. P. 1975. Influence of environment on mesquite phenology. M.S. Thesis, Texas Tech University, Lubbock. 95 p.

Goen, J. P., and B. E. Dahl. 1982. Factors affecting budbreak in honey mesquite in west Texas. J. Range Manage. 35:533-534.

Goodman, P. J., and M. M. Caldwell. 1971. Shrub ecotypes in salt desert. Nature 232:571-572.

Haas, H. H., R. E. Meyer, C. J. Scifres, and J. H. Brock. 1973. Growth and development of mesquite, p. 10-19. In Mesquite - Growth and development, management, economics, control, and uses. Research Monogr. No. 1. Texas Agriculture Experiment Station. Texas A and M University, College Station.

Hanson, J. D. 1982. Effect of light, temperature and water stress on net photosynthesis in two populations of honey mesquite. J. Range Manage. 35:455-458.

Harper, J. L., J. N. Clatworthy, I. H. McNoughton, and G. R. Sagar. 1961. The evolution and ecology of closely related species living in the same areas. Evolution 15:209-227.

Harper, J. L., P. H. Lovell, and K. G. Moore. 1970. The shapes and sizes of seeds. Ann. Rev. Ecol. and Syst. 1:327-356.

Hyder, D. N., A. C. Everson, and R. E. Bemet. 1971. Seedling morphology and seeding failures with blue grama. J. Range Manage. 24:287-292.

Hyder, D. N., W. R. Houston, and J. B. Burwell. 1976. Drought resistance of blue grama as affected by atrazine and N fertilizer. J. Range Manage. 29:214-216.

Itai, C., A. Richmond, and Y. Vaadia. 1968. The role of root cytokinins during water and salinity stress. Israel Bot. 17:187-195.

Itai, C., and Y. Vaadia. 1971. Cytokinin activity in water. Stressed shoots. Plant Physiol. 47:87-90.

Jewer, P. C., and L. O. Incloo. 1980. Promotion of stomatal opening in the grass Anthephora pubescens Nees by a range of natural and synthetic cytokinins. Planta 150:218-221.

Larcher, W. 1980. Physiological plant ecology (Second Edition). Springer-Verlag, New York. 303 p.

Marks, J. 1950. Vegetation and soil relationship in the lower Colorado Desert. Ecology 31:176-193.

McDonough, W. T. 1977. Seed physiology, p. 155-184. In Sosebee, R. E. (ed), Rangeland plant physiology. Range Series No. 4. Society for Range Management, Denver, Colorado.

McLendon, T. 1979. Ecotypic variation in mesquite seedlings along an edaphic gradient. Ph. D. Dissertation. Texas Tech University, Lubbock. 138 p.

McNoughton, S. J. 1966. Thermal inactivation properties of enzymes from Typha latifolia L. ecotypes. Plant Physiol. 41:1736-1738.

McNoughton, S. J. 1967. Photosynthetic system II: Racial differentation in Typha latifolia. Science 156:1363.

McNoughton, S. J. 1972. Enzymatic thermal adaptations: The evolution of homeostasis in plants. Am. Nat. 106:165-172.

McNoughton, S. J. 1973. Comparative photosynthesis of Quebec and California ecotypes of Typha latifolia. Ecology 54:1260-1270.

Meidner, H. 1967. The effect of kinetin on stomatal opening and the rate of intake of carbon dioxide in mature primary leaves of barley. J. Exp. Bot. 18:556-561.

Meyer, R. E., and R. W. Bovey. 1982. Establishment of honey mesquite and huisache on a native pasture. J. Range Manage. 35:548-550.

Meyer, R. E., J. D. Hanson, and A. J. Dye. 1983. Correlation of honey mesquite response to herbicides with three plant variables and soil water. J. Range Manage. 36:5.

Mooney, H. A., B. B. Simpson, and O. T. Solbrig. 1977. Phenology, morphology, physiology, p. 26-43. In Simpson, B. B., (ed.) Mesquite - Its biology in two desert scrub ecosystems. US/IBP Synthisis Series No. 4, Dowden, Hutchinson, and Ross, Inc. Stroudsburg, Pa.

Morey, P. R., and B. E. Dahl. 1975. Histological and morphological effects of auxin transport inhibitors on honey mesquite. Bot. Gaz. 136:274-280.

Musselman, R. C., D. T. Lester, and M. S. Adams. 1975. Localized ecotypes of Thuja occidentalis L. in Wisconsin. Ecology 56:647-655.

Nilson, E. T., M. R. Sharifi, P. W. Rundel, W. M. Jarrel, and R. A. Virginia. 1983. Diurnal and seasonal water relations of the desert phreatophyte Prosopis glandulosa (honey mesquite) in the Sonoran Desert of California. Ecology 64:1381-1393.

Palmblad, I. G. 1968a. Comparative response of closely related species to reduced competition. I. Scenecio sylvaticus and S. viscosus. Can. J. Bot. 146:225-228.

Palmblad, I. G. 1968b. Competition in experimental populations of weeds with emphasis on the regulation of population size. Ecology 49:26-34.

Parsons, D. L., and R. E. Sosebee. 1974. Influence of Ethrel on phenological development in honey mesquite. J. Range. Manage. 27:165-166.

Peacock, J. T., and C. McMillan. 1965. Ecotypic differentation in Prosopis (mesquite). Ecology 46:35-51.

Phillips, W. S. 1963. Depth of roots in soil. Ecology 44:424.

Romberger, J. A. 1963. Meristems, growth, and development in woody plants. USDA Forest Service Tech. Bull. No. 1293. 214 p.

Rundel, P. W., E. T. Nilson, M. R. Sharifi, R. A. Virginia, W. M. Jarrell, D. H. Kohl, and G. B. Shearer. 1982. Seasonal dynamics of nitrogen cycling for a Prosopis woodland in the Sonoran Desert. Plant and Soil 67:343-353.

Schulze, E. D. 1986. Carbon dioxide and water vapor exchange in response to drought in the atmosphere and in the soil. Ann. Rev. Plant Physiol. 37:247-274.

Scifres, C. J., C. R. Kienast, D. J. Kienast, and D. J. Elrod. 1973. Honey mesquite seedling growth and 2,4,5-T susceptibility as influenced by shading. J. Range Manage. 26:58-60.

Seipp, W. W. 1982. Carbohydrate reserve patterns in honey mesquite during bud-break. M. S. Thesis, Texas Tech Univeristy. Lubbock. 83 p.

Shearer. G., D. H. Kohl, R. A. Virginia, B. A. Bryan, J. L. Skeeters, E. T. Nilsen, M. R. Sharifi, and P. W. Rundel. 1983. Estimates of N_2-fixation from variation in the natural abundance of ^{15}N in Sonoran Desert ecosystems. Oecologia (Berlin) 56:365-373.

Simpson, B. B. and O. T. Solbrig. 1977. Introduction, p. 1-25. *In* B. B. Simpson (ed.), Mesquite - Its biology in two desert scrub ecosystems. U.S./IBP Synthesis Series No. 4. Dowden, Hutchinson, and Ross, Inc. Stroudsburg, Pa.

Sosebee, R. E. and C. H. Herbel. 1967. Temperature and moisture effects on seedling emergence and initial growth of range plants, p. 40. *In* Agron. Abstr.

Sosebee, R. E. 1974. Herbicide plus various additives for follow-up control of shredded mesquite. J Range Manage. 27:53-55.

Sosebee, R. E., B. E. Dahl, and J. P. Goen. 1973. Factors affecting mesquite control with Tordon 225 mixture. J. Range Manage. 26:369-71

Stephensen, A. G. 1981. Flower and fruit abortion: proximate causes and ultimate functions. Ann. Rev. Ecol. Syst. 12:253-279.

Stubblefield, R. E. 1986. Carbohydrate trends in silverleaf nightshade (*Solanum elaeagnifolium*). M. S. Thesis. Texas Tech University, Lubbock. 72 p.

Thomas, G. W., and R. E. Sosebee. 1978. Water relations of honey mesquite--a facultative phreatophyte, p. 414-418. *In* D. Hyder (ed.) First Internat. Rangeland Congress., Proc. Society for Range Management. Denver, Colo.

Turner, N. C. 1986. Crop water deficits: A decade of progress. Advances in Agronomy. 39:1-52

Turresson, G. 1922a. The species and variety as ecological units. Hereditas 3:100-113.

Turresson, G. 1922b. The genotypical response of the plant species to the habitat. Hereditas 3:211-350.

Ueckert, D. N., L. L. Smith, and B. L. Allen. 1979. Emergence and survival of honey mesquite seedlings on several soils in west Texas. J. Range Manage. 32:284-287.

Vickery, R. K., Jr. 1950. An experimental study of the races of the *Mimulus guttatus* complex, p. 272. *In*, Seventh Internat. Bot. Congress, Proc.

Virginia, R. A., and W. M. Jarrell. 1983. Soil properties in a mesquite-dominated desert ecosystem. J. Soil Sci. 47:138-144.

Wardlaw, I. F. 1967. Effect of water stress on translocation in relation to photosynthesis and growth. Aust. J. Biol. Sci. 20:25-39.

Wendt, C. W., R. H. Haas, and J. Runkles. 1967. Influence of selected environmental variables on the transpiration rate of mesquite. Agron. J. 60:382-384.

Werk, K. S., J. Ehleringer, I. N. Forseth, C. S. Cook. 1983. Photosynthetic characteristics of Sonoran Desert Winter Annuals. Oecologia (Berlin) 59:101-105.

Wester, D. B., B. E. Dahl, and P. F. Cotter. 1986. Effects of pattern and amount of simulated rainfall on seedling dynamics of weeping lovegrass and kleingrass. Agron. J. 78:851-855.

Whalley, R. D. B., and J. B. Burfitt. 1972. Ecotypic variation in *Avena fatua* L. *A. sterilis* L. (*A. ludoviciana*), and *A. barbata* Pott. in New South Wales and Southern Queensland. Aust. J. Agr. Res. 23:799-810.

Wilkinson, R. E. 1980. Ecotypic variation of *Tamrix pentandra* epicuticular wax and possible relationship with herbicide sensitivity. Weed Sci. 28:110-113.

Wilson, A. M. 1971. Amylase synthesis and stability in crested wheatgrass seeds at low water potentials. Plant Physiol. 48:541-546.

Wilson, A. M., D. N. Hyder, and D. D. Briske. 1976. Drought resistance characteristics of blue grama seedlings. Agron. J. 68:479-484.

Wilson, A. M., and J. A. Sarles. 1978. Quantification of growth, drought tolerance and avoidance of blue grama seedlings. Agron. J. 70:231-237.

Wilson, A. M., and D. D. Briske. 1979. Seminal and adventitious root growth of blue grama seedlings on the Central Plains. J. Range Manage. 32:209-213.

Wilson, R. T., D. R. Krieg, and B. E. Dahl. 1974. A physiological study of developing pods and leaves of honey mesquite. J. Range Manage. 27:202-203.

Wilson, R. T., B. E. Dahl, and D. R. Krieg. 1975. Carbohydrate concentrations in honey mesquite roots in relation to phenological development and reproductive condition. J. Range Manage. 28:286-289.

Wooten, J. W. 1973. Edaphic factors in species and ecotype differentiation of *Sagittaria*. J. Ecol. 61:151-156.

Workman, J. P., and N. E. West. 1969. Ecotypic variation of *Eurotia lanata* populations in Utah. Bot. Gaz. 130:26-35.

Zelitch, I. 1979. Photorespiration with whole tissues, p. 353-367. *In* M. Gibbs, and E. Latzko (eds.), Photosynthesis II. Photosynthetic carbon metabolism and related processes. Springer-Verlag, New York.

WILDLAND SHRUB DIEOFFS IN UTAH: AN APPROACH TO UNDERSTANDING THE CAUSE

David L. Nelson, Kimball T. Harper, Kenneth C. Boyer,
Darrell J. Weber, B. Austin Haws, and James R. Marble

ABSTRACT: A survey of the 1984-1985 shrub dieoff in eastern and central Utah showed 734,500 acres of rangeland to be affected. Additional unsurveyed dieoffs occurred in western Utah valleys. Shrub species affected include shadscale, fourwing saltbush, budsage, winterfat, horsebrush, narrowleaf low rabbitbrush, and others. Although earlier dieoffs have been associated with severe drought, the recent dieoff was associated with a record high precipitation period. Possible interacting factors discussed include overgrazing, winter injury, drought, salinity-anaerobiosis, insects, disease, and host genetics. Information from the literature on these factors, the nature of past shrub dieoffs reported, and environmental factors coincident with the recent high precipitation period (1977-1986) are considered in formulating an approach to understanding the cause.

BACKGROUND

Utah range resource managers, including those of the Bureau of Land Management, U.S. Department of Interior, Utah Division of Wildlife Resources and Utah Department of Agriculture; range scientists from Utah State University, Brigham Young University, and Forest Service, U.S. Department of Agriculture; as well as ranchers and other private land owners, have registered concern and interest in a recent widespread loss of wildland range shrubs. The Bureau of Land Management (BLM) estimated that 1 million acres (Boyer 1986) have been affected in Utah alone. Other Great Basin States, Nevada and Idaho, have shrub populations that are also affected. Conditions of low vigor, decline, and mortality have been noted primarily in shadscale (Atriplex confertifolia), but also among fourwing saltbush (Atriplex canescens), big sagebrush (Artemisia tridentata ssp. tridentata and A. t. ssp. wyomingensis), budsage (A. spinescens), black sagebrush (A. nova), winterfat (Ceratoides lanata), greasewood (Sarcobatus vermiculatus), horsebrush (Tetradymia spinosa), spiny hopsage (Grayia spinosa), bitterbrush (Purshia tridentata), and narrowleaf low rabbitbrush (Chrysothamnus viscidiflorus ssp. viscidiflorus var. stenophyllus). This immense "dieoff" (unexplained partial to complete death of shrubs on sites up to hundreds of acres or more) occurred in the later portion of an historically record high-precipitation period between 1977 to 1986 (see section on drought and figure 1). Because the plant species affected include shrubs important for forage and habitat on the 40 million acres of salt desert extending across the Great Basin and northern Colorado Plateau (Holmgren and Hutchings 1972; Hutchings and Stewart 1953) this large-scale shrub dieoff is of importance to wild and domestic ungulate and other wildlife interests.

Of more intrinsic importance are the ecological implications in the shadscale zone. Because these phenomena have been little studied, the nature and direction of plant succession in dieoff areas is not well understood. For the shadscale zone, successional unknowns are posed by the presence of exotic annual plants such as cheatgrass (Bromus tectorum), halogeton (Halogeton glomeratus), Russian thistle (Salsola iberica), tansy mustard (Descurainia sophia), summercypress (Kochia scoparia) and others. Disturbed sagebrush-grass vegetation on the Snake River Plains of south central Idaho succeeds through a series of annuals (Piemeisel 1951) terminating often in a cheatgrass climax that is perpetuated to some extent by range wildfire. Cheatgrass flourished as shadscale declined during the recent high moisture period. Because few of the major shrubs of the shadscale zone sprout following fire, widespread wildfire could have the potential for converting cold desert shrublands to annual herb communities. This would also increase the danger of fires spreading to adjacent sagebrush-grass and pinyon-juniper zones.

Eighty-three percent of the western United States is covered with forest-range vegetation (USDA Forest Service, Forest-Range Task Force 1972). Of this, 51 percent is dominated by shrubs, constituting an estimated 820 million acres (Plummer 1974). Shrubs are also a component of grasslands, and in forests shrubs occupy open spaces and understory. Thus, the western United States is predominately an arid to semiarid

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David L. Nelson is Plant Pathologist, Shrub Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT; Kimball T. Harper is Professor of Botany, Darrell J. Weber is Professor of Botany, and James R. Marble is Graduate Student, Department of Botany and Range Science, Brigham Young University, Provo, UT; Kenneth C. Boyer is Range Conservationist, Utah State Office, Bureau of Land Management, U.S. Department of Interior, Salt Lake City, UT; and B. Austin Haws is Professor of Entomology, Emeritus, Department of Biology, Utah State University, Logan, UT.

shrubland habitat, one that has evolved in response to interacting combinations of drought, poor soil aeration, low soil mineral nutrients, shade, fire, and winter cold (Stebbins 1975). Aside from more utilitarian values (animal forage, recreation lands, firewood, medicinals, biomass raw materials), this immense shrubland system provides watershed, influences air quality and climate, and supports numerous animal life forms. Understanding the biology of this system is an unavoidable fundamental that is urgently in need of study.

THE RECENT SHRUB DIEOFF

Dieoff Survey

A partial BLM survey (USDI-BLM 1985-1986) of the Utah shrub dieoff by range conservationists in the Moab, Richfield, and Vernal Districts showed 734,500 acres affected in four shrub-dominated communities as follows: black sagebrush 8,000, big sagebrush 16,000, fourwing saltbush 20,500 and shadscale 690,000 acres. Where fourwing saltbush was the dominant shrub, shadscale was a common associate. Where shadscale was dominant, community composition ranged from almost pure stands of that species to associations in which fourwing saltbush, budsage, winterfat, hopsage, horsebrush, low rabbitbrush, and other species were subdominants. Mortality ranged from 10 to almost 40 percent in fourwing saltbush stands. Mortality percentages were higher (20-95 percent) in shadscale communities.

In western Utah (not included in the survey), entire shadscale populations died on many valley bottoms, on slight rises, and in upland depressions. On peripheral valley slopes, only scattered dead and dying plants were more typical. Scattered dead and dying plants were also typical of all other shrub species affected.

Utah Division of Wildlife Resources (Stevens 1985) reported spotty to extensive areas of dieoff or low vigor of big sagebrushes, mountain rubber rabbitbrush (Chrysothamnus nauseosus ssp. salicifolius), bitterbrush, and Atriplex spp. in areas located more in the mountain shrub zone. Bitterbrush and big sagebrush mortality was found over several hundred acres in what appeared to be a rather distinct elevational belt, along the east side of Skull Valley, Tooele County, UT.

Nature of Dieoff

The most widespread mortality of shrubs was reported to have occurred in the summers of 1984 and 1985. Partially dead shrubs have continued to decline and die. Insect damage and disease were most frequently judged to be the cause of death with occasional mention of drought, winterkill, or high water table. Intensity of large animal use (primarily deer), for the most part, was considered a factor only with Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) decline, especially in the Browns Park area of the Vernal BLM District. As of spring 1986 there appeared to be little or no regeneration in most areas of extensive shrub mortality or decline. Native perennial grasses, cheatgass, and other weedy annuals have flourished in dieoff areas. Among the big sagebrushes, especially Wyoming big sagebrush, affected stands showed symptoms of low vigor and slow decline, not mass death. Decline symptoms included slow growth, low seed production, shoot dieback, and occasional death of the entire plant. With the Atriplex spp., there was not an obvious relationship between age or size and plant death. Fourwing saltbush dieoff affected populations had low vigor, severe basal decay, rootlet mortality, and root borer activity in decayed tissue and heart wood. In some areas heavy animal use was also evident.

In the shadscale zone, shrub mortality, especially of Atriplex confertifolia, occurred as mass dieoffs. Death of entire populations occurred over hundreds of acres. Dying, as well as apparently healthy, plants in dieoff zones typically had severe fine rootlet mortality and active rot and decay in larger roots. Shoot dieback was commonly associated with death of the corresponding portion of a plant root system. In valley bottoms, mid-valley rises, and upland depressions, death of entire populations occurred during a short period, perhaps 1 to 2 years. At higher elevations, and on peripheral valley slopes and hills, dieoff was characteristically a scattered slow-decline and death that continues to the present. There were, however, shadscale populations even on valley bottoms and adjacent to dieoff areas that were little if at all affected. Dieoff among associated shrubs (such as budsage, winterfat, narrowleaf low rabbitbrush, and horsebrush), particularly in western Utah valleys, usually involved a slow decline rather than mass deaths. Mortality of small rootlets, rot of larger roots, and shoot dieback were also associated with these species.

Other than grasshopper damage (covered in a later section), no large-scale epidemic of defoliating insects has been associated with any shrub species involved in the recent dieoff. Mealybugs were common on shadscale in some areas and appear to be widespread in the Great Basin and adjacent areas. When infestations were found, they were usually either on lower stems protected by duff or living portions of the upper fractured tap root below the soil surface. Occasionally root-borer insect larvae were found in decayed heartwood tissues of shadscale roots.

Mass shadscale dieoff occurred on diverse sites and soil types. In western Utah, dieoff occurred on the heavy silty-clay soils of valley bottoms, sandy-clay soils of mid-valley rises, and gravelly soils of alluvial fans. In the Grand River Valley area of the Colorado Plateau in east-central Utah, extensive shadscale dieoff occurred on gravelly to sandy soils derived from Book Cliff alluvium.

CAUSE OF SHRUB DIEOFF

The purpose of this section is to discuss the following environmental factors as possible causes of extensive shrub dieoff: large animal use, winter injury, drought, soil salinity, anaerobiosis, insect epidemics, and plant disease. Throughout, emphasis is on the Chenopodiaceae (most specifically shadscale) because it was the most severely affected by dieoff. Therefore, the interacting role of Atriplex genetics, evolution, and distribution is an important consideration. Rather than basing this discussion on an exhaustive review of original research, syntheses of reviewers of various subjects will be used where available. For each potential causal factor, the nature of the mechanism of plant injury will be briefly described as a basis for comparing relevant information in the literature to mortality of wildland shrub species of interest. Then, using the preceding largely subjective description and assessment of the recent shrub dieoff, each environmental factor will be evaluated as to its possible role in the dieoff.

Large Animal Use

There are many reports of shrub mortality resulting from domestic and big game animal use (Frischknecht and Harris 1973; McArthur and others 1988; Stewart and others 1940). Range scientists have long studied the influence of animal feeding on plant productivity and vigor, and on community composition and succession (Ellison 1959, 1960). In the shadscale zone, browsing by livestock tends to favor shadscale (Holmgren and Hutchings 1972). This response is less related to its innate palatability than to its spiny nature. If animal feeding causes decline and death of specific shrub species and alters community composition, the decline occurs over extended periods of time except when use is extreme (Blaisdell and Holmgren 1984). Long-term controlled studies on the influence of browsing can be confused by shorter term, overriding, events such as drought and insect epidemics (Holmgren and Hutchings 1972; West 1982). When large-scale death and decline of shrubs is caused by overgrazing it is clearly restricted to the area of overuse.

Large animal use did not appear to be a factor in the recent shrub dieoffs, except as a possible intensifying or predisposing factor (perhaps in such recent cases as fourwing saltbush decline in San Juan County, UT, and Wyoming big sagebrush decline at Browns Park in Daggett County, UT). The extensive areas of shadscale dieoff did not appear to be correlated with intensive livestock use.

Winter Injury

Winter injury has been implicated as a cause of mass shrub dieoff in the intermountain West. Unseasonal high precipitation periods or overland flow of water from high-intensity summer storms could possibly predispose plants to winter injury or drought. Death of shrubs over large areas has been observed following overland water flows at the Forest Service Desert Experimental Range and elsewhere in west-central Utah by Ralph C. Holmgren (Forest Service) and Kimball T. Harper (Brigham Young University). If plants remain at least partially submerged for extended periods, death could result from oxygen-deficient root systems. However, overland water flow late in the season can stimulate abundant new shoot growth. This succulent growth may not reach sufficient winter dormancy in time for winter freezing or drought hardiness in time to adjust top growth to water deficits during the following summer's dryness.

Cottam (1937) reported extensive damage to several shrub species of the Sonoran zone in southwestern Utah following an unusual cold period. In a survey report of Nelson and Tiernan (1983), damage was reported for 36 shrub species following the unusually low precipitation winter of 1976-1977 in the western United States. In the mountain-shrub zone Ceanothus, Arctostaphylos, Juniperus, Artemisia, and others were most likely killed or damaged by winter injury while low-elevation cold-desert shrubs such as Atriplex, Ceratoides, Grayia, Sarcobatus, and others were likely damaged by drought alone. Almost complete winter-kill of mountain big sagebrush stands (Artemisia tridentata ssp. vaseyana) occurred on an estimated 138,000 acres while partial kill occurred in many other areas. Other reports of winterkill or injury include bitterbrush (Jensen and Urness 1979; Smith and others 1965), fourwing saltbush (Van Epps 1975), and Ceanothus (Stickney 1965).

Winter injury is a rather broadly encompassing term and its mechanisms are diverse. Plants receive winter injury by freezing because of insufficient cold-hardiness, or in cold-tolerant plants, from the lack of winter dormancy. Winter injury can also be caused by desiccation resulting from transpiration when the root system is frozen, or the soil is frozen or too dry for supply of needed water. The most critical periods are usually in early or late winter. With winterkill dieoffs, a fairly reliable diagnosis can be based on the uniqueness of symptoms and coincident climatic episodes.

Studies on the 1976-1977 mountain big sagebrush winterloss in southwestern Idaho at the Reynolds Creek Experimental Watershed (Hanson and others 1982; Schumaker and others 1979) supplied experimental evidence to support winter injury as the cause. Mortality was near 100 percent where sagebrush plants were normally covered by deep snow and slight in areas of normally shallow cover. Below average soil moisture and frozen soil during periods when temperatures were high enough for plant respiration and transpiration implicated physiological drought as the cause of winter kill.

Apparently no similar large-scale winter injury event occurred during 1977-1986, a period of high precipitation and heavy winter snow cover. However, winterkill from freezing of nondormant plants could account for the death of big sagebrush and bitterbrush along an elevational belt on the east face of Skull Valley in Tooele County, UT, in the spring of 1985.

Drought

Although the severe overgrazing-caused deterioration of grass on intermountain rangelands during the early 1930's was the focus of attention, the first notice of shrub dieoff came with the drought of 1934, the culmination of a 14-year dry spell. On the upper Snake River Plains of southeastern Idaho, Pechanec and others (1937), studying the effects of the 1934 drought on the sagebrush-grass type, found a 46.8 percent reduction in cover of all shrubs relative to the 1932 cover: Artemisia tripartita 48.7, Chrysothamnus puberulus 29.1, Purshia tridentata 49.1, and Tetradymia canescens ssp. inermus 48.8 percent. In the shadscale zone of the Great Basin, episodic dieoffs of shadscale and associated shrubs have been observed over the years and the cause was usually attributed to drought. Stewart (1935) observed a general mortality of forage plants of "appreciable magnitude" on the winter ranges of Utah and Nevada during the 1931-1934 drought period. At the Desert Experimental Range, he reported a general mortality of 20 percent for shadscale and white sage (winterfat). Mortality reached 60 percent in heavily grazed areas. Little rabbitbrush mortality was apparently less, judged so by Stewart because of less grazing pressure resulting from lower palatability. Also at the Desert Experimental Range during the drought periods of 1933-1934 and 1942-1943 Hutchings and Stewart (1953) and Hutchings (1954) referred to a widespread shadscale mortality of 20-30 percent, while black sagebrush, budsage, and winterfat had little mortality. Ellison (1959) called attention to drought as an environmental factor in plant succession citing an apparent drought-caused dieoff of little rabbitbrush at the Desert Experimental Range in 1952. A combination of drought, competition, and moderate grazing tended to favor Artemisia nova (black sagebrush) over little rabbitbrush. His study site was a nonsaline bajada on the west side of Antelope Valley where shadscale does not occur. However shadscale dieoff could have occurred on the heavy soils of valley bottoms because in other reports shadscale is considered to be less drought tolerant than little rabbitbrush. Insect damage has also been suspected as a factor in reduction of little rabbitbrush (Holmgren and Hutchings 1972).

Following the severe drought of 1958-1961, Holmgren (1963) studied the effects of drought in the shadscale and sagebrush zones of western Nevada in the Carson Desert area. He sampled 23 locations in a 50- by 150-mile area for shrub death and cover reduction on different sites and soil types. With all species on every site there was a reduction in cover. On the various sites, total cover reduction ranged from 20 to 75 percent. With some shrub species the extent of death was influenced by soil and site: budsage mortality was generally less than 10 percent in the sagebrush zone, but complete in the sandy soils of the upper shadscale zone; smooth horsebrush (Tetradymia glabrata) in the shadscale zone died out completely on shallow dune sands that were overlying lacustrine silt-clays, but only 30 percent death occurred on sites with deep sand. Mortality of shadscale and little greasewood (Sarcobatus baileyi) was about 20 percent regardless of site. Other shrubs (winterfat, fourwing saltbush, spiney hopsage, big sagebrush, and Nevada jointfir (Ephedra nevadensis) had light mortality. Thus, with this drought, in the shadscale zone of western Nevada, there tended to be a shift in shrub species composition from budsage and horsebrush to hopsage, winterfat, and jointfir, with some reduction in shadscale.

During the 1958-1961 drought, shadscale dieoff was also extensive at the Desert Experimental Range (Holmgren 1988). Similar dieoffs of shadscale were observed there in the drought of 1971-1972 and 1976-1977 (Blaisdell and Holmgren 1984). Holmgren and Hutchings (1972) concluded that many shadscale plants "die when one dry year follows directly upon another." Shrub dieoff in the shadscale zone, although regularly associated with drought periods, has not been studied in detail except for the Holmgren (1963) study. There is no experimental evidence for concluding a droughtkill, cause-and-effect relationship based on an established water-deficit death-point.

There are, however convincing leads based on a comparison of weather records and observed dieoffs. A review of annual precipitation over a 50-year period at the Desert Experimental Range and observed shadscale dieoffs supports the Holmgren-Hutchings (1972) rule (fig. 1). When annual precipitation was 1.0 or more inches below the 50-year average (6.29 inches) or 4.5 inches or less for 2 consecutive years, noticeable shadscale dieoffs usually occurred. During this period the only 2-year drought period of apparent exception was 1955-1956. This was part of an 11-year dry spell (1948-1959) that terminated with the dieoff of 1958-1961 (Holmgren 1963). Shadscale dieoff probably occurred in 1952-1953 based on the notice of little rabbitbrush drought-kill of that time (Ellison 1959). A mass dieoff at this time could have masked the potential 1955-1956 episode because of insufficient time for shadscale regeneration. The record of shadscale dieoffs is sketchy; perhaps because dieoffs were common and because the assumption that droughts caused the dieoffs was apparently well accepted by 1954 (Hutchings 1954, p. 14), some mass dieoffs could have gone unreported at that time. Interpretation of biological phenomena, relevant to annual precipitation on a water-year basis (October through September) has the uncertainty of timing. Heavy precipitation during the last week in September for example would have little biological effect for that amount in that year but could be considerable for the following year.

During the period 1977-1984 (with a 1-year exception, 1982-1983) well above average precipitation occurred. This was the longest sustained wet period in the 50-year history of the Desert Experimental Range. The mass shadscale dieoff that occurred in 1983-1985 in the absence of drought was observed in many areas of the Great Basin shadscale zone. This

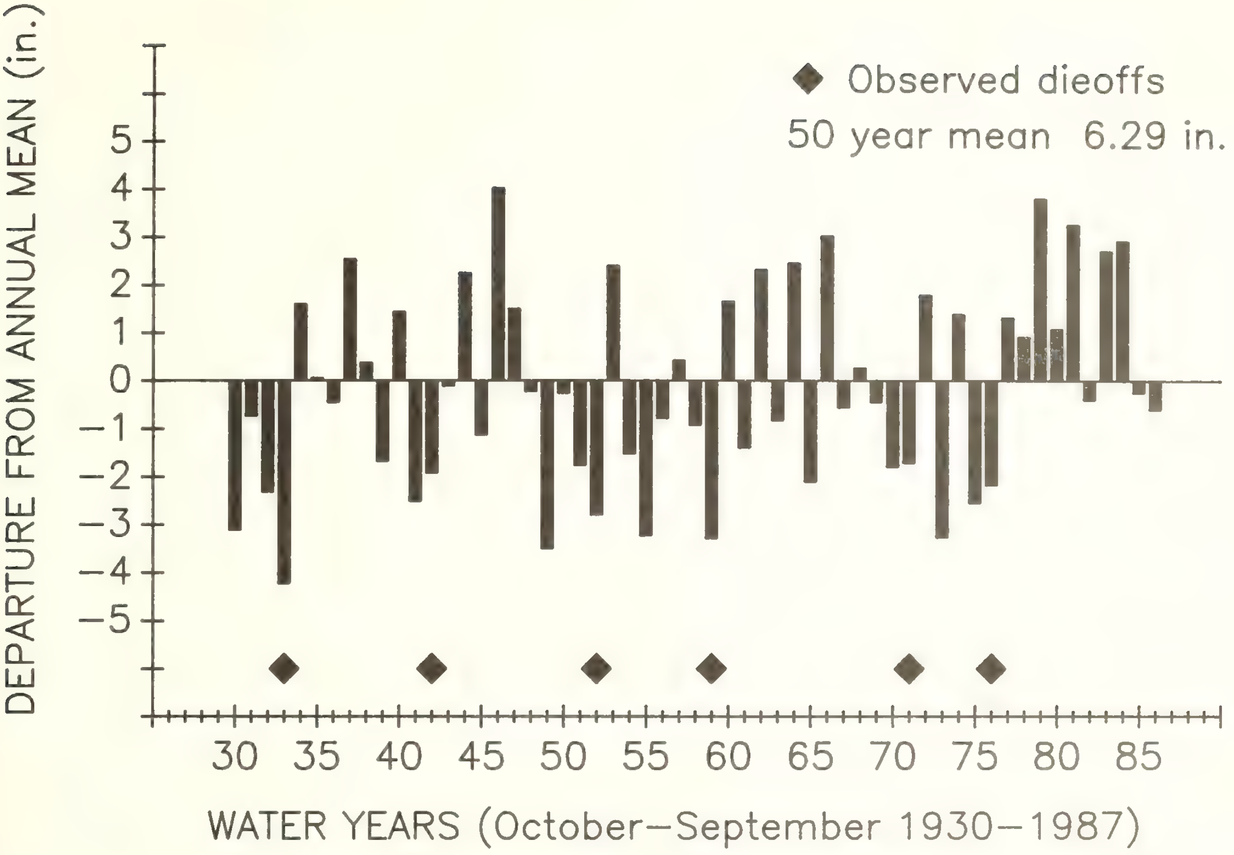

Figure 1--Association of observed shadscale dieoffs with drought periods at the Desert Experimental Range. Amounts prior to 1934-1935 were extrapolated from Deseret, Utah (74 miles distance) weather records and after 1983-1984 from Wah Wah Ranch (14 miles distance).

was the only major shadscale dieoff of record that was not associated with drought. Unfortunately no weather records or observations on shrub dieoff have been made at the Desert Experimental Range after 1983-1984.

A Sketch of Great Basin Physiography, Climate, and Vegetation

The following sketch of Great Basin habitat is intended as a background for consideration of soil salinity and anaerobiosis as potential causes or predisposing factors of mass shrub dieoff.

The north-south oriented basins and mountain ranges that comprise the Great Basin formed during the Rocky Mountain uplift. With the continued rise of the Sierra Nevada during the Pleistocene and the consequent climatic aridity of Great Basin country, outward precipitation drainage to the ocean was slowly terminated. As a consequence, vegetation changed from more mesic forests, woodlands, and grasslands to dominance of drought-tolerant shrubs (Axelrod 1950; Axelrod and Ting 1960), the evolution of which still continues. Great Basin valleys are filled to varying degrees with outwash of the sedimentary deposits of ancient inland seas that raised during formation of present bordering mountain ranges. Peripheral valley alluvial slopes or bajada composed of coarse gravelly soil at their upper limits gradually change to more gravelly sandy, then loamy soils at their lower reaches. Pleistocene lakes filled numerous Great Basin valleys; with their disappearance, sedimentary lake deposits developed into the silty to heavy clay soils presently found. The larger valleys or basins may therefore have large expanses of very uniform soil.

The hydrologic cycle of the Great Basin is one of internal drainage and evaporation of precipitation coming as summer rain to valleys and mountains, and winter snows primarily to the mountains. Higher valleys, if not topographically closed, drain to lower basins. Thus, salts carried by snowmelt and intense summer storm runoff or groundwater movement accumulate in a declining gradient outward from the lowermost portions of closed valleys, or even perched, closed depressions at higher elevations. It is in these niches that the halophytic shrubs, primarily chenopods, have been and continue to be evolving.

Large fluctuations in amount of precipitation could result in the possible fluxing of water tables in certain valley bottoms, and in others the existence of ephemeral saline lakes or playas with evaporative surfaces. A somewhat banded, perplexing mosaic of vegetation radiates from these salt playas and marshes. Species composition changes along an osmotically induced stress gradient (Branson and others 1967): from fungi, algae, pickleweed (*Allenrolfea occidentalis*), and alkali sacaton (*Sporobolus airoidea*) (the salt marsh); through saltsage (*Atriplex tridentata*), greasewood, desert molly (*Kochia americana*), shadscale, winterfat, and budsage (the salt-desert-shrub or shadscale zone); to the big sagebrush and pinyon-juniper zones. Community distribution and composition of any given site is probably determined by species adaptation (by evolution) to tangled interactions of such factors as edaphic and climatic situations, interplant competition, and animal herbivory. Explanation of observed patterns remains somewhat puzzling (Billings 1949; Branson and others 1967; Gates and others 1956; Goodman 1973; Shantz 1925; Stewart and others 1940; West 1982; West and Ibrahim 1968).

For an enchanting account of the physiography, climate, and cold desert vegetation of the Great Basin see Holmgren (1984). Included are references to basic works on the subject.

Soil Salinity

There are an estimated 54.4 million acres (22 million ha) of saline soils in the 11 western States (McKell and others 1986). Naturally saline and sodic soils occur primarily in areas of semiarid climate and in closed drainage basins where soils are derived from shale, siltstone, and other sedimentary deposits of ancient inland salt-water seas. With insufficient precipitation for leaching or in closed drainage basins salts accumulate in the upper soil profile. The most common ions involved in saline soils are: Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-. Salts of these ions can form in various combinations and amounts. Soils are considered saline (adversely affecting most domestic plants) at an electrical conductivity of 4 mmho/cm at soil saturation, with the range of plant tolerance among plant species being at about half to twice this amount (Bernstein 1975).

Much of the present information on the effects of soil salinity in plants has come from agricultural crop experimentation; the processes for desert plants are not thought to be basically different (Caldwell 1974; Kleinkopf and others 1975; Wallace and others 1973). Different interacting environmental elements, however, require special further consideration in the assessment of salinity effects on desert plants (Caldwell 1974): low soil moisture, low atmospheric humidity, summer-winter temperature extremes, sporadic temperature and precipitation fluctuations, low available soil nitrogen.

Symptoms of adverse salinity in plants include slower growth, stunting, smaller more succulent leaves, darker green leaves, and leaf wilting. With woody plants, leaf tip-burn and necrosis commonly occur. At high salt concentrations (the thresholds of which are determined by specific plant adaptation, halophyte or nonhalophyte), the limits of protective mechanisms are exceeded, membrane selectively is lost, and there is an influx of salt into the shoots with lethal results. The symptoms induced by adverse salinity result from an interaction of three general processes. First, failure of plants (halophytes and nonhalophytes) to compensate internal osmotic potential with an increased salinity-caused reduction in osmotic potential of the soil solution leads to a series of events: turgor reduction, water stress, stomatal closure, reduction in gas exchange and consequential reduction in transpiration, and reduced photosynthesis. Second, excess Na^+ and Cl^- accumulation, as well as excesses of other elements (boron, selenium, lithium), can cause toxicity and necrosis. Third, nutritional imbalances usually involving ratios also occur. Adjustments of plants to adverse salinity requires additional energy for osmotic regulation and maintenance respiration. Energy deficit is further complicated by reduced formation of energy-rich molecules (adenosine triphosphate, ATP) used in metabolism of available carbohydrates.

Various protective mechanisms for salt tolerance have evolved. Resistance to water deficits occurs by formation of fewer stomata, stomatal closure, increased leaf cuticle thickness, and root proliferation which increases the root-leaf surface ratio. Both nonhalophytes and halophytes (halophytes at a higher magnitude) actively accumulate electrolytes to maintain an osmotic gradient in the face of increasing soil salinity, to maintain turgor. Osmotic adjustment or regulation occurs by compartmentalization of salts in vacuoles that are balanced osmotically by nontoxic organic solutes in the cytoplasm. Tolerance to salt toxicity also occurs partially from these neutral cytoplasmic organic solutes through protection of root membranes and by selective translocation. Reduction of ion concentration occurs through increased shoot growth and leaf succulence, and by salt excretion through salt glands, such as the bladder trichomes of *Atriplex* (Lipschitz and Waisel 1982; Schirmer and Breckle 1982). Plants also isolate ions in old leaves, leaf petioles, tracheids, and roots.

These generalities on salinity symptoms and protective mechanisms in plants were derived from, and more specifics can be obtained from, various reviews and associated basic works on the subject (Bernstein 1975; Caldwell 1974; Flowers and others 1977; Greenway and Munns 1980; Pasternak 1987).

Great Basin habitats, especially old Lake Bonneville and Lahontan basins, certainly present the potential for fluctuations in soil salinity in response to fluctuations in precipitation. High and low precipitation extremes, either from soil drying (upward movement of salts by capillarity and lack of leaching) or soil moisture saturation (raised water tables) could result in increased salinity. Although there have been studies on shrubs and soil salinity in the Great Basin none have involved interaction with mass shrub dieoff. There are undocumented reports of mass shrub dieoff in Australia when salts moved upward in the soil profile during extended drought periods. Increased soil salinity could be a factor in the drought-associated dieoffs of shadscale at the Desert Experimental Range referred to above. Studies on salt tolerance of shadscale zone vegetation in the Great Basin and adjacent areas have focused on seedling germination and growth (Chatterton and McKell 1969; Kleinkopf and others 1975; Richardson and McKell 1980; Springfield 1966; Workman and West 1969); and shrub distribution (Branson and others 1967; Gates and others 1956; Goodman 1973; Goodman and Caldwell 1971; Moore and others 1972). Extrapolation of this information as a clue to shrub dieoff is rather indirect, although the ordination of species by tolerance of mature plants to salinity or osmotic stress (increasing order of tolerance: big sagebrush, black sagebrush, budsage, winterfat, shadscale, desert molly, greasewood, saltsage, mat saltbush) (Branson and others 1967; Goodman 1973) proposes constructs for hypothesizing.

During the recent shrub dieoff in the upper shadscale zone where Wyoming big sagebrush and shadscale are intermixed, cases of severe shadscale dieoff occurred, whereas big sagebrush remained healthy; an event not likely to result from elevated soil salinity. Around the fringes of a rising Great Salt Lake where shadscale and saltsage intermix, shadscale died but saltsage remained healthy; an event likely to result from a level of salinity or anaerobiosis excessive for shadscale but not saltsage. The lethal salinity threshold for the various intermountain cold desert shrubs is not known.

Anaerobiosis

Prolonged full saturation of soil with water, severely reducing oxygen diffusion into the soil, leads to an anaerobic soil environment (waterlogging). Roots of plants as well as soil microorganisms must then contend with life at little or no soil oxygen (anaerobiosis). The recent above-average precipitation period (1977-1986) across the Great Basin and adjacent area could have resulted in instances of soil waterlogging or high soil moisture for extended periods. Prolonged high precipitation could result in raised water tables in certain basins or valleys. Intense rainfall or snowmelt could result in accumulation of water (resulting in soil waterlogging) on basin floors or depressions where impervious or semi-impervious soil strata slow drainage. A near tripling of the size of Malheur Lake in Oregon (Ganskopp 1986), the resurgence of Sevier Dry Lake and rapid rise of the Great Salt Lake in Utah are notable evidence of an unusually high precipitation period.

Damage from temporary or prolonged waterlogging of especially nontolerant plants (particularly accelerated at warm to high temperatures) is manifest by various symptoms (Drew and Lynch 1980). These include a slowing or cessation of root growth, senescence of older leaves, shoot wilting, leaf epinasty and abscission, and eventual death of the entire plant. Waterlogging during cold weather causes little damage, probably because of the low rate of plant respiration. As further outlined by Drew and Lynch (1980) plant injury from anaerobiosis possibly results from four processes: 1) accumulations of toxins that form in anaerobic soil or roots, 2) lack of water uptake through damaged root membranes, 3) hormone imbalance resulting from malfunction of leaf and root metabolism and reduced translocation, and 4) mineral deficiency resulting from inhibited uptake and translocation or reduced amounts of nutrients available in the soil.

Following soil waterlogging, existing soil oxygen is used within a few minutes to hours by roots and soil microorganisms. In general, soil microorganisms can exist at a much lower soil oxygen level than roots of higher plants, thereby increasing the advantage of potentially pathogenic types. An early vital system thought to fail in the plant is the production of energy rich molecules (ATP) that drive metabolic systems (Givan 1968). In a short time (as a result of ATP deficit), the root cell membranes begin losing differential permeability and there is a greatly increased efflux of cytoplasmic metabolites into the soil (Hiatt and Lowe 1967). Dormant spores of certain fungi (including potential pathogens) are stimulated to germinate by these nutrients. Increased root exudation during plant oxygen-stress would tend to increase the zone of influence. Fungal germ tubes and mobile zoospores follow exudate-nutrient gradients to infect rootlets. If soil salinity is associated with waterlogging (a likely event at Great Basin salt desert sites) there would also be an increased influx of potentially toxic soil-water ions (Na^+, Cl^-) (Barrett-Lennard 1986) that could further stress the plant and possibly accumulate to lethal amounts. A combined waterlogging-saline environment can either increase or decrease vulnerability of plants to infection by pathogenic organisms depending on the stress-state of the host plants, as well as favorability of the waterlogged environment to a specific pathogen. Activity of some fungi (watermolds or pythiaceous fungi) is enhanced by high soil-water matric potentials. However these fungi may also be inhibited by proliferation of anaerobic microbial antagonists under this environment.

To various degrees, plants, both waterlogging tolerant and nontolerant, make some adjustments for anaerobiosis. Physiological, metabolic, and anatomical adjustments occur that provide some tolerance or avoidance of oxygen deficiency (Drew and Lynch 1980). Responses that are evidently under hormonal control, initiated by anaerobiosis, cause a slowing of growth, a redistribution of mineral nutrients to young leaves and a closing of stomata which reduce both nutrient and water stress. Alternate metabolic pathways, particularly with waterlogging-tolerant species, impart some control over formation of the toxic end products of anaerobic respiration. Aerenchyma (tissue with specialized air channels) forms in newly developing adventitious roots and in existing stems by cell lysis. Aerenchyma apparently enables increased movement of oxygen from shoots to roots (Drew and Lynch 1980).

There is little reported information on anaerobiosis as a factor in the shrub dieoffs of consideration here. Although some dieoff symptoms are similar to those discussed above for anaerobiosis, they are not easily distinguished from symptoms induced by drought, salinity, and vascular wilt diseases. Symptom induction by any of these factors could result from disruption of the same basic physiological processes (for example, maintenance of turgor). Relevant to anaerobiosis of desert shrubs is the general conclusion that big sagebrush is intolerant of poorly drained, fine-textured, highly moist soils (Branson 1956; Fosberg and Hironaka 1964; USDA Forest Service 1937; Vallentine 1980). Lunt and others (1973) gave experimental evidence in support of this. Big sagebrush and creosote bush required a relatively high oxygen diffusion rate (0.50 and 0.45 mg cm^{-2} min^{-1} respectively) compared to bursage (Franseria dumosa) at 0.30, a rate requirement more comparable to the generally high moisture tolerance of agricultural plants.

A study of shrub tolerance to inundation and high water tables around a rising Malheur Lake in Oregon during 1983-1984 (Ganskopp 1986) indicated Wyoming big sagebrush was most sensitive to high water levels followed by rabbitbrush (Chrysothamnus viscidiflorus) and greasewood. After 21 to 28 days inundation of big sagebrush, complete mortality occurred; many plants were also killed when the water table came within 6 to 10 cm of the soil surface. Decline and death of rabbitbrush and greasewood followed sagebrush by about 7 and 16 days respectively. Reduced vigor appeared to correspond to degree and duration of high water levels.

Extensive dieback of leafy bladder saltbush (Atriplex vesicaria) (1,130,000 to 531,000 ha reduction) occurred on the Riverine Plain area of southeastern Australia during 1979-1983 (Clift and others 1987). Widespread dieback occurred 2 years after an exceptionally high precipitation season. Although determining the cause was not an objective of their study, evidence seemed to implicate a causal link between waterlogging, increased salinity, pathogens, and insects followed by drought toward the end of the dieback period.

Certainly there were sites and instances during the recent high precipitation period in the Great Basin where waterlogging persisted long enough to cause shrub death directly or secondarily through plant predisposition by creating an environment conducive to microbial pathogen activity. In Rush Valley and other valleys of western Utah, in the zone where Wyoming big sagebrush and shadscale intermingle, there were instances of severe shadscale dieoff with little or no effect on sagebrush. Given that shadscale is more tolerant of waterlogging and salinity (perhaps not well established) one could conclude that other causal factors such as host-specific insects, microbial pathogen activity, or differential virulence of these agents between hosts, explain the differential mortality of shadscale and sagebrush.

Insect Epidemics

To affect the cross section of shrub species in the proportions observed in the recent dieoff would require a large-scale, multispecies insect epidemic. The nature and stability of the insect environment (weather, host, food state, predators, parasites, diseases, genetic polymorphism, and many other factors) interacting in complexity determine the latent or epidemic state of eruptive insects as reviewed by Wallner (1987). Primary epidemiological factors, influencing a broad spectrum of insects (such as a period of unusually high precipitation and consequent luxuriant growth of host plants) would be required to concurrently initiate the epidemic state of such a multispecies epidemic. In arid zones, weather fluctuations (precipitation, temperatures) tend to be more extreme than in humid zones. Aberrations in insect populations commonly follow extreme events and eruptive insects are usually more affected than endemic or non-outbreak insects. Both the direct and indirect influences of plant stress or stimulation result in an asynchrony in insect-host relationships. Examples of such altered relationships include: 1) increased phenotypic homogeneity, thus food supply; 2) modified host nutritional quality such as increased amino acid levels; 3) overwintering mortality of insects and consequent population genetic shifts; and 4) insect antagonist (predators, parasites, pathogens) population shifts (Wallner 1987).

A basic phenomenon of insect, as well as microbial epidemiology, is the conducive role of host geographic range, site-habitat uniformity, and host genetic homogeneity (monocultures). Shadscale frequently occurs in vast genetically homogeneous, fairly even-aged populations on rather uniform soils and sites as a result of recent shadscale evolution and occupancy of Pleistocene lake bottoms of the Great Basin by that species (Stutz 1978; Stutz and Sanderson 1983).

In their review of rangeland entomology, Watts and others (1982) noted the absence of information on browse plant insects of western North American rangelands, attributing the lack of detailed biological information to the ill-defined value of the resource to the ranching economy. Literature and observations on the impact of harmful insects and diseases on shrubs of western big game ranges (Furniss and Krebill 1972), and literature and unpublished data for insects affecting shrubs of the Pacific Northwest (Furniss and Barr 1975) have been reviewed and these publications again demonstrate a general lack of information in this area. The shrub species of interest in the foregoing reports are from the mountain-shrub zones associated with forest trees and riparian sites. An illustrative account of both beneficial and injurious rangeland insects of the western United States was published by the Four Corners Commission (1982). Haws and others (1988) prepared an index to information on insects of wildland shrubs of the western United States. Little experimental research has been conducted on insects associated with shrubs of the shadscale zone. There are, however, probably many rather obscure studies, primarily made by insect collectors, that have indirect relevance to shadscale zone insect epidemiology. For example, lizards of the shadscale zone consume large quantities of a broad spectrum of insects (Knowlton 1934; Knowlton and Janes 1932, 1934). Thus, how do weather extremes or range management practices influence lizard populations?

Grasshoppers are of major importance on western rangelands, clearly surpassing all other insects in destructiveness (Anderson 1972). There are 13 grasshopper species in the intermountain region of potential threat (Hewitt 1977). Food habitat and host specificity vary among the species (Parker 1985; Sheldon and Rogers 1978) and, though not clearly understood, outbreaks appear to be closely related to the previous year's precipitation and additive daily temperature maximum thresholds (Gage and Mukerji 1977; Nerney and Hamilton 1969). Overwintering success, current hatch survival, and favorable weather for forage production are also involved. A large scale grasshopper epidemic occurred in central to northern Utah in 1984-1985, during the recent shrub dieoff period. Defoliation and debarking activity occurred on Utah juniper (Juniperus osteosperma), rubber rabbitbrush, big sagebrush, fourwing saltbush, shadscale, winterfat, and budsage (McCawley 1985). Based on a transect survey, various degrees of shadscale and black sagebrush mortality followed the severe defoliation of the previous year. The boundaries of shadscale dieoff, however, either did not correspond to the limits, or far exceeded the boundary of readily evident signs of grasshopper damage. Grasshopper feeding, thus, probably indirectly enhanced dieoff in some areas rather than being a direct cause.

The moth Aroga websteri is an important defoliator of sagebrush, especially species of the subgenus Tridentatae, throughout the Great Basin. Hsiao (1986) and Hsiao and others (1972-1976) have recently studied and reviewed the biology and demography of Aroga on big sagebrush. Substantial areas of sagebrush have been killed following several successive years of defoliation by Aroga. During the recent shrub dieoff, this defoliator apparently remained in a latent state and was not involved.

Another severe defoliator of sagebrush is the beetle, Trirhabda pilosa, reported to cause extensive damage in British Columbia (Banham 1961; Pringle 1960). There has been a recent report of isolated activity of Trirhabda sp. beetles on sagebrush in Utah (Haws and Boyer 1986), but no evidence of widespread activity of this insect in the Great Basin. Fourwing saltbush has been defoliated, and apparently killed, in southern Idaho by a beetle (Monoxia sp., Cyrhsomelidae) and casebearing moth larvae (Psychidae) (Meadows and others 1984).

A snout moth (Pyradidae) is reported to have damaged shadscale heavily on about 20,000 acres in the Raft River Valley of southern Idaho in 1951 (Hutchings 1952). Apparently because of associated mortality, the severe defoliation by the larvae was considered to be the cause of death. No recent epidemic activity of this insect is known.

Similarly, Sharp and Sanders (1978) concluded that an infestation of shadscale between 1955-1958, also in southern Idaho, by a scale insect (Orthezia annae), (actually a mealybug-like insect, Homoptera:Ortheziidae) caused large-scale death of the host. Mealybugs have been observed on the upper taproots and lower branches of shadscale throughout the area of recent shrub dieoff in the Great Basin and adjacent areas. Scale insects and mealybugs have sucking mouth parts and damage plants directly by feeding or by injecting toxins. They can also transmit viral plant pathogens. Because of their feeding habit, evaluation of damage caused by these insects is more ambiguous than, for example, that caused by a defoliating insect. There is no experimental evidence available to demonstrate that mealybugs can kill shadscale; but based on agricultural crop experience (Rohrbach and others 1988), there is little reason to believe that a mealybug-virus complex cannot kill shadscale.

Plant Disease

Nature and Predisposition--Plant disease is an injurious physiological process induced by pathogenic agent(s). Plant pathogenic agents may be either biotic (fungi, bacteria, viruses, mycoplasmas, and others) or abiotic (temperature extremes, atmospheric toxicants, oxygen deficiency, mineral nutrient deficiency, and others). Vigorous, healthy plant growth increases host resistance to facultative parasites but is more favorable to infection and activity by obligate parasites. Physical (nongenetic) and biological environmental factors that are injurious initiate plant stress, thereby increasing susceptibility to potential pathogens (the plant is predisposed to disease development). In the absence of biotic pathogens and the cessation of nongenetic stress, the plant will recover. Nonaggressive facultative parasites commonly enter and become established in resistant as well as nonresistant plants, then remain latent until the plant becomes predisposed. Should predisposition occur, the disease process continues to develop and symptom expression takes place. Stress is thus more important in disease development than in parasitic establishment. A pathogenic mode of action common among facultative parasites is to kill host tissue in advance of the invading thallus and then to live saprophytically on the dead tissue, thereby determining the character of disease symptoms (such as tissue maceration or rot). The induction of increased host susceptibility by predisposing factors occurs through a variety of mechanisms: for example, the suppression of host defense-response systems.

The symptoms of shrub dieoff discussed above, if in fact induced by plant disease, are more typical of facultative parasites (wilt, root rot, rootlet necrosis) than obligate parasites (rust, smut, mildew). If plant disease is a major determinant in shrub dieoff, careful consideration of known predisposing factors and the presence of facultative parasites seems relevant. Also important is the occurrence of an environment favorable for activity of these parasites; for example, water molds require a film of water in the soil for zoospore mobility. Successful infection and development of a disease usually require a rather intricate interaction of the host and pathogen in a common environment. Disease epidemics occur when a particularly favorable triangle of these elements occurs; this would differ to some degree with each host-pathogen-environment combination. For a facultative parasite a favorable triangle for an epidemic might include the following: 1) a genetically homogeneous host population, 2) an aggressive facultative parasite at an adequate population density, and 3) environmental stress factors optimal for host predisposition, yet favorable for parasite activity including antagonist relations.

Basic nongenetic environmental factors that stress plants, predisposing them to disease development include: 1) soil water-oxygen (drought and waterlogging); 2) stressful temperature (cooking, chilling, or freezing); and 3) toxicants (soil-water ions, atmospheric). Such factors predispose plants to disease by modifying or disrupting physiological processes: 1) metabolic production of toxins that inhibit parasites; 2) anatomical changes that form mechanical barriers against parasites; and 3) maintenance of critical carbohydrate levels. Biological predisposing factors that can act directly or indirectly through similar mechanisms include: 1) defoliation; 2) wounding; 3) rootlet "nibbling" by fungi or nematodes; and 4) loss of root symbionts (nitrogen fixing or mycorrhizal organisms). The foregoing discussion follows reviews on plant predisposition to disease by Yarwood (1959), Colhoun (1973), and Schoeneweiss (1975).

Considering the unusually high precipitation of the period (1977-1986) there would seem to have been adequate predisposing environmental conditions for disease of epidemic proportions (see above discussion on salinity-anaerobiosis). Prolonged stress (in the absence of biotic pathogens) related to physical soil factors acting individually or in combination could also have induced abiotic disease.

Fungal Pathogens--There is little information in the literature on diseases caused by facultative-type parasites for wildland shrubs of the sagebrush-shadscale zone. A number of *Artemisia* species were affected by a wilt and root rot disease in an experimental planting at Ephraim, UT (Nelson and Krebill 1981). Although the plants were growing in a heavy clay soil, it was a big sagebrush site prior to present agricultural use. Common facultatively parasitic fungal genera (*Fusarium*, *Sclerotinia*, *Rhizoctonia*, *Alternaria*, and others) were associated with the disease that was probably predisposed by abiotic soil factors and biotic factors incident to agriculture. Similar fungi were also associated with a basal-decay disease commonly affecting fourwing saltbush on several wildland sites in Utah (Nelson and Welch 1984). During the apparent drought-induced dieoff of shadscale in Nevada (1976-1977), *Fusarium* was isolated from the roots and basal stems of dying shadscale (Nelson 1977-1978). Preliminary isolation studies on the recent dieoff reveal that similar associated fungi (*Fusarium*, *Cephalosporium*, *Alternaria*, *Pythium*) are present, not only in dying shadscale but also on associated low-vigor budsage and winterfat. These organisms can also be isolated from apparently healthy (symptomless) plants suggesting a pattern of infection, establishment, and subsequent latency. These fungal genera are cosmopolitan and include saprophytes as well as facultative parasites of a potentially pathogenic nature. They are apparently widespread components of the sagebrush-shadscale zone flora.

The rather insidious nature of damage to mature plants (reduced growth and vigor) caused by "root nibblers" such as *Pythium* has long been recognized (see review in Wilhelm 1965). Activity by this fungus could be an important biological predisposer to more virulent root rot or vascular wilt pathogens, especially during cool, high-precipitation periods that are favorable to its (*Pythium*) proliferation.

Among agricultural crops, members of the Chenopodiaceae, particularly *Beta vulgaris*, are vulnerable to this class of pathogens (Whitney and Duffus 1986) as well as others. A large group of these fungi (*Pythium*, *Phytopthora*, *Phoma*, *Rhizoctonia*, *Fusarium*, *Verticillium*) induces various diseases including: seedling damping off, root rot, leaf spot and blight, yellows, and vascular wilt.

Mycorrhizal Relations--Various reviews of research (Gerdemann 1968; Marx 1972; Marks and Kozlowski 1973; Mosse 1973; Zak 1964) primarily with forest trees, indicate that endo- and ectomycorrhizal fungal symbionts benefit the host in various ways such as: 1) deterrence of root pathogens; 2) absorption of both inorganic and organic nutrients, 3) increase of resistance to drought and high temperature damage, and 4) production of growth-regulating hormones. The mycorrhizal relations of sagebrush-shadscale zone shrubs have been little studied, but most species are probably mycorrhizal (Allen 1983; Gerdemann 1968; Lindsey 1984). Soil environmental factors known to influence mycorrhizae (Mosse 1973; Slankis 1974) include: 1) soil nutrient status (organic and inorganic), 2) soil moisture and oxygen levels, 3) soil pH, 4) presence and abundance of plant root exudates and fungal growth hormones, 5) rhizosphere effect, and 6) soil temperature. Failure of mycorrhizal symbioses, because of the adverse status of these factors and the subsequential influence on the host, could lead to plant stress. Potential instances when the above factors could have either benefited or damaged mycorrhizal associations have been discussed above with regard to the recent shrub dieoff. Because both mycorrhizal fungi and mycorrhizae are highly aerobic, the most likely factor to have affected shrub mycorrhizae would be prolonged high soil moisture and associated anaerobiosis. Alteration of root physiology as well as a direct effect on mycorrhizal fungi, by anaerobiosis, could interact to the detriment of mycorrhizae and thus increase root susceptibility to pathogens. As further reviewed by Slankis (1974), numerous nonmycorrhizal fungi and some bacteria of the rhizosphere stimulate mycorrhizal infection and growth by release of extracellular thiamin and auxins. Thus deterrence of rhizosphere aerobes by anaerobiosis would tend to inhibit mycorrhizae and indirectly predispose hosts to disease.

Nematode Relations--Feeding by nematodes cannot only induce plant disease, but also nematodes can interact with plant viruses and fungal pathogens to adversely influence mycorrhizae. In their reviews, Endo (1975) and Powell (1971) described several nematode-fungus disease complexes (Fusarium and Verticillium wilt, Phytopthora root rot) and also described the role of nematodes in transmission of plant pathogenic viruses. Nematode feeding on ectomycorrhizal roots disrupts the fungal mantle and nutrient flow (Barham and others 1974). This not only damages the symbiotic association but also exposes rootlets to entry by other pathogens. Severe parasitic nematode damage to members of the Chenopodiaceae, particularly B. vulgaris, has been studied since the mid 1800's but the status of nematodes on chenopods of the shadscale zone remains unknown. Plant/parasitic nematode population dynamics are influenced by soil type, temperature, moisture, aeration, osmotic potential, organic matter, pH (Norton 1979), as well as biological interactions. Abiotic environments favorable to host vigor are also generally favorable to nematode activity (analogous to obligate fungal parasites). However, when plant stress factors subsequently occur that lower tolerance to nematodes, damage becomes more severe (Barker and Olthof 1976). Nematode damage generally tends to be less severe in heavy-textured soil than in light. The areas of more severe recent shadscale dieoff were where the soil was heavy. Thus there does not appear to be evidence for an environment particularly conducive to a nematode-caused epidemic in the recent shadscale dieoff.

Atriplex Genetics, Evolution, and Distribution

Plant populations confront the environment with an evolved "genetic system" ("the totality of the hereditary mechanisms controlling variability," Solbrig 1970). Character and amplitude of the system determine survival, continued evolution, or extinction of species in the face of stable to changing environments. Homogeneity of host genetics, host phenology, and host environment are among the critical elements conducive to insect and disease epidemics. Considering the nature of the various possible causal agents of the recent dieoff, discussed above, the status of soil environment is especially suspect (consider for example, soilborne biotic pathogens inducing root rot and vascular wilt; mealybugs that operate below the duff or soil surface).

Present populations of perennial Atriplex in and immediately around the Great Basin are thought to have migrated and evolved from populations of northern Mexico where adaptation through evolution in a desert environment has long existed. This might have occurred during a period of climatic aridity in western North America just prior to the last Bonneville pluvial about 12,000 years ago (Stutz 1978). Atriplex has apparently evolved a flexible system for synthesis of richly diversified genotypes through mutation, interspecific hybridization, allo- and autopolyploidy, and subsequent introgression and segregation (Stutz 1978). And as further portrayed by Stutz (1978), with the recession of Pleistocene lakes in what is now the Great Basin, new habitats were exposed in which a diversity of Atriplex genotypes were tested. The stage was thus set for an explosive evolution of new species.

Diploid Atriplex confertifolia (shadscale) populations apparently emigrated from areas peripheral to montane glaciers to occupy and evolve adaptation to upper elevation zones not submerged by developing Pleistocene lakes. Descendant diploid populations still remain in what is now the upper big sagebrush and pinyon-juniper zone (Stutz and Sanderson 1983). As the lakes receeded and exposed topographically and edaphically new uniform habitats, shadscale populations began to be tested. Genetic combinations that by chance were uniquely suited to the new sites rapidly expanded horizontally across old lake bottoms to form sometimes vast almost pure stands of genetically homogeneous races (Stutz and Sanderson 1983). Barriers to outcrossing with bordering diploid populations tend to maintain the homogeneous integrity of new polyploid races. Chromosome analysis confirms the presence of diploid populations above the level of Pleistocene Lake Bonneville and races at various different polyploid levels below that elevation (Stutz and Sanderson 1983).

Contrary to the model of epidemiology in a dynamically balanced inter- or intraspecifically diverse natural plant community (Dinoor and Eshed 1984), that operating on the playas of Pleistocene lake bottoms in the Great Basin may be more analogous to that of an agricultural monoculture. Major portions of the shadscale zone could be climatically, edaphically, and plant genotypically homogeneous, and thereby a haven for pest outbreaks and dieoffs.

Considering the capacity for generation of genetic variability in Atriplex, should not evolution produce increasing resistance to factors that cause mass dieoff among taxa of the genus? Or, as a contrary, speculation could suggest that vulnerability to mass dieoff is a mechanism for plant redistribution on the site, from islands of shadscale halophytic salt accumulation. Demographic factors such as mechanisms for preservation of seed stores to survive "needed" dieoffs could be more important than dieoffs to the long-term survival of shadscale. Perhaps the more basic problem is to reconcile range management interests with a largely unknown shadscale ecology, while protecting its "genetic-system" store from a too-abrupt man-caused environmental change, such as the introduction of weedy exotic and perceived desirable plants into the shadscale zone.

SUMMARY-CONCLUSIONS

Overuse of shrubs by ruminant animals can be largely discounted as a cause of the recent dieoff. Overgrazing could possibly function as a secondary weakening factor and then only in restricted areas as in the case of fourwing saltbush stands in Dry Valley, San Juan County, UT, and in Wyoming big sagebrush stands on Taylor Flat, Browns Park Area, Daggett County, UT. In the majority of dieoff areas, there is seldom evidence of overgrazing.

Symptoms and patterns of the dieoff events of 1984-1985 discount winter injury as a cause, except in a few cases. Death of bitterbrush and big sagebrush occurred in an elevational belt among the east side of Skull Valley, Tooele County, UT (spring of 1985). That episode was suggestive of winter injury during a valley temperature inversion, because the damaged area followed a sharp line across a uniform population of mountain big sagebrush above which no injury occurred.

Although there is some good evidence to establish drought and associated factors as the major cause of episodic shadscale dieoffs prior to 1977, the recent dieoff was associated with an historically high precipitation period, not drought.

Salinity and anaerobiosis are soil environmental factors likely to be associated with extended high precipitation periods. In areas subject to high water tables or in small depressions and large basins where impervious soil strata would impede soil-water drainage, prolonged waterlogging and thus anaerobiosis is likely to occur. Considering the geomorphology of the Great Basin and adjacent areas, these sites must be common. Both excessive salinity and prolonged anaerobiosis can kill plants directly, induce abiotic disease, or predispose plants to biotic pathogens. However, there are many extensive and small or scattered dieoff sites in the shadscale zone (mid-valley rises, slopes, and ridges) where prolonged waterlogging, even during high precipitation, is unlikely.

Insects in a latent or endemic equilibrium state do some damage to plants without resulting in mass dieoff. The majority of insect species associated with dieoff in the shadscale zone were undoubtedly in an endemic (nonoutbreak) state. Most species, such as the Aroga sagebrush defoliator, known to cause large-scale death when in an epidemic state, were not obvious during the recent dieoff. The grasshopper epidemic occurring in 1985 caused severe damage but was far more limited in scope than the dieoff phenomenon. The mealybugs of shadscale could cause major dieoffs based on agricultural parallels, but this does not account for dieoffs in all areas or of other shrub species. The single report of shadscale damage from mealybugs does not associate the epidemic with high or low precipitation.

Soilborne microorganisms, soil salinity, and anaerobiosis seem to be the environmental factors, of those considered, that would be modified or enhanced the most by high soil moisture extremes. Prolonged springtime high soil moisture could favor the proliferation of facultative soilborne parasites such as Pythium. Pythium-induced fine feeder-rootlet mortality could result in plant predisposition to other pathogens (Fusarium) or result in desiccation and nutrient stress during low-moisture periods of summer. These fungi generally have wide distribution and a wide range of hosts. Dieoff could then be possible on sites having extended high soil moisture but insufficient for high salinity and prolonged anaerobiosis. Plant stress, from all other factors considered in this discussion, could influence plant predisposition to disease development. The range in severity of dieoffs could result from variable interaction of these factors and the subsequent degree of predisposition.

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REFERENCES

Allen, Michael F. 1983. Formulation of vesicular-arbuscular mycorrhizae in Atriplex gardneri (Chenopodiaceae): seasonal response in cold desert. Mycologia. 75: 773-776.

Anderson, N. L. 1972. The assessment of range losses caused by grasshoppers. In: Hemming, C. F.; Taylor, H. C., eds. International study conference--Current and future problems in acridology: Proceedings; 1970; London. London: Center for Overseas Pest Research: 173-179.

Axelrod, Daniel I. 1950. Evolution of desert vegetation in western North America. In: Axlerod, Daniel I. Studies in Late Tertiary paleobotany; Contributions to paleobotany. Publ. 590. Washington, DC: Carnegie Institution of Washington: 215-323.

Axelrod, Daniel I.; Ting, William S. 1960. Late Pliocene floras east of the Sierra Nevada. University of California Publications in Geological Sciences. 39(1): 1-118.

Banham, F. L. 1961. Distribution of Trirhabda pilosa Blake (Coleoptera: Chrysomelidae) attacking big sagebrush in the interior of British Columbia. Proceedings of the Entomological Society of British Columbia. 58: 38-30.

Barham, Richard O.; Marx, Donald H.; Ruehle, John L. 1974. Infection of ectomycorrhizal and nonmycorrhizal roots of short leaf pine by nematodes and Phytophthora cinnamomi. Phytopathology. 64: 1260-1264.

Barker, K. R.; Olthof, T. H. A. 1976. Relationship between nematode population densities and crop responses. Annual Review of Phytopathology. 14: 327-353.

Barrett-Lennard, E. G. 1986. Effects of waterlogging on the growth and NaCl uptake by vascular plants under saline conditions. Reclamation and Revegetation Research. 5: 245-261.

Bernstein, Leon. 1975. Effects of salinity and sodicity on plant growth. Annual Review of Phytopathology. 13: 295-312.

Billings, W. D. 1949. The shadscale vegetation zone of Nevada and eastern California in relation to climate and soils. The American Midland Naturalist. 42: 87-109.

Blaisdell, James P.; Holmgren, Ralph C. 1984. Managing intermountain rangelands salt-desert shrub ranges. Gen. Tech. Rep. INT-163. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 52 p.

Boyer, K. C. 1986. [Personal communication]. Estimates of shrub dieoff acreage based on vegetative mapping and observations. Salt Lake City, UT: U.S. Department of Interior, Bureau of Land Management, Utah State Office.

Branson, F. A. 1956. Range forage production changes on a water spreader in southeastern Montana. Journal of Range Management. 9: 187-191.

Branson, F. A.; Miller, R. F.; McQueen, I. S. 1967. Geographic distribution and factors affecting the distribution of salt desert shrubs in the United States. Journal of Range Management. 20: 287-296.

Caldwell, Martyn M. 1974. Physiology of desert halophytes. In: Reimond, Robert J.; McQueen, William H., eds. Ecology of halophytes. New York, London: Academic Press: 355-378.

Chatterton, N. Jerry; McKell, Cyrus M. 1969. Atriplex polycarpa: 1. Germination and growth as affected by sodium chloride in water culture. Agronomy Journal. 61: 448-450.

Clift, D. K.; Semple, W. S.; Prior, J. C. 1987. A survey of bladder saltbush (Atriplex vesicaria Heward ex Benth) dieback on the Riverine Plain of southeastern Australia from the late 1970's to 1983. Australian Rangeland Journal. 9: 39-48.

Colhoun, John. 1973. Effects of environmental factors on plant disease. Annual Review of Phytopathology. 11: 343-364.

Cottam, Walter P. 1937. Has Utah lost claim to the Sonoran Zone? Science. 85: 563-564.

Dinoor, A.; Eshed, N. 1984. The role and importance of pathogens in natural plant communities. Annual Review of Phytopathology. 22: 443-466.

Drew, M. C.; Lynch, J. M. 1980. Soil anaerobiosis, microorganisms, and root function. Annual Review of Phytopathology. 18: 37-66.

Ellison, Lincoln. 1959. Role of plant succession in range improvement. In: Ecology of grasslands. Washington, DC: American Association for the Advancement of Science: 308-321.

Ellison, Lincoln. 1960. Influence of grazing on plant succession of rangelands. The Botanical Review. 26: 1-78.

Endo, B. Y. 1975. Pathogenesis of nematode-infected plants. Annual Review of Phytopathology. 13: 213-238.

Flowers, T. J.; Troke, P. F.; Yeo, A. R. 1977. The mechanism of salt tolerance on halophytes. Annual Review of Plant Physiology. 28: 89-121.

Fosberg, M. A.; Hironaka, M. 1964. Soil properties affecting the distribution of big and low sagebrush communities in southern Idaho. Special Publ. 5: Plant physiology and soil-range relationships. American Society of Agronomy: 230-236; Res. Pap. 618. Moscow, ID: Idaho Agricultural Experiment Station.

Four Corners Commission. 1982. An introduction to beneficial and injurious rangeland insects of the western United State. Haws, B. Austin, compiler, project coordinator. Cooperating State Agriculture Experiment Stations-Arizona, Colorado, Nevada, New Mexico, Utah. Special Rep. 23. Logan, UT: Utah Agricultural Experiment Station. 64 p.

Frischknecht, Neil C.; Harris, Lorin E. 1973. Sheep can control sagebrush on seeded range if... Utah Science. 34: 27-30.

Furniss, Malcolm M.; Barr, William F. 1975. Insects affecting important native shrubs of the northwestern United States. Gen. Tech. Rep. INT-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 64 p.

Furniss, Malcolm S.; Krebill, R. G. 1972. Insects and diseases of shrubs on western big game ranges. In: McKell, Cyrus M.; Blaisdell, James

P.; Goodin, Joe R., eds. Wildland shrubs-their biology and utilization: International symposium; 1971 July; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 218-226.

Gage, Stuart H.; Mukerji, M. K. A perspective of grasshopper population distribution in Saskatchewan; an interrelationship with weather. Environmental Entomology. 6: 469-479.

Ganskopp, David C. 1986. Tolerances of sagebrush, rabbitbrush, and greasewood to elevated water tables. Journal of Range Management. 39: 334-337.

Gates, Dillard H.; Stoddart, L. A.; Cook, C. Wayne. 1956. Soil as a factor influencing plant distribution on salt-deserts of Utah. Ecological Monographs. 26: 155-175.

Gerdemann, J. W. 1968. Vescular-arbuscular mycorrhiza and plant growth. Annual Review of Phytopathology. 6: 397-418.

Givan, Curtis V. 1968. Short-term changes in hexose phosphates and ATP in intact cells of Acer pseudoplatanus L. subjected to anoxia. Plant Physiology. 43: 948-952.

Goodman, P. J. 1973. Physiology and ecotypic adaptations of plants to salt desert conditions in Utah. Journal of Ecology. 61: 473-494.

Goodman, P. J.; Caldwell, M. M. 1971. Shrub ecotypes in a salt desert. Nature. 232: 571-572.

Greenway, H.; Munns, Rana. 1980. Mechanisms of salt tolerance in nonhalophytes. Annual Review of Plant Physiology. 31: 149-190.

Hanson, Clayton. L; Johnson, Clifton W.; Wright, J. Ross. 1982. Foliage mortality of mountain big sagebrush (Artemisia tridentata subsp. vaseyana) in southeastern Idaho during the winter of 1976-1977. Journal of Range Management. 35: 142-145.

Haws, B. A.; Boyer, K. C. 1986. [Personal communication]. Investigation of a Trirhabda sp. beetle outbreak on mountain big sagebrush in Summitt County, UT. Logan, UT: Utah State University, Department of Biology.

Haws, B. Austin; Roe, Alan H.; Nelson, David L. 1988. Index to information on insects associated with western wildland shrubs. Gen. Tech. Rep. INT-248. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 296 p.

Hewitt, George B. 1977. Review of forage losses caused by rangeland grasshoppers. Misc. Publ. 1348. U.S. Department of Agriculture, Agricultural Research Service. 22 p.

Hiatt, A. J.; Lowe, Richie H. 1967. Loss of organic acids, amino acids, K, and Cl from barley roots treated anaerobically and with metabolic inhibitors. Plant Physiology. 42: 1731-1736.

Holmgren, Ralph C. 1963. Effect of the 1958-61 drought on some range plant communities of valleys in the western Great Basin; Summary report. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT. 6 p.

Holmgren, Ralph C. 1984. The Great Basin cold desert: some physical geography. In: Tiedemann, Arthur R.; McArthur E. Durant; Stutz, Howard C.; Stevens, Richard; Johnson, Kendall L., compilers. Proceedings of the symposium on the biology of Atriplex and related chenopods: 1983 May 2-6; Provo, UT. Gen. Tech. Rep. INT-172. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 108-113.

Holmgren, Ralph C. 1988. [Personal Communication]. June. Provo, UT: U.S. Department of Agriculture, Forest Service, Shrub Sciences Laboratory.

Holmgren, Ralph C.; Hutchings, Selar S. 1972. Salt desert shrub response to grazing use. In: McKell, Cyrus M.; Blaisdell, James P.; Goodin, Joe R., eds. Wildland shrubs-their biology and utilization; International symposium; 1971 July; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 153-164.

Hsiao, T. H. 1986. Biology and demography of sagebrush defoliator and its impact on big sagebrush. In: McArthur, E. Durant; Welch, Bruce L., eds. Proceedings--symposium on the biology of Artemisia and Chrysothamnus. 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 191-198.

Hsiao, T. H.; Green, T. W.; Kirkland, R. L.; Temte, A. K. 1972-1976. Demographic studies of sagebrush insects as function of various environmental factors. US/IBP Desert Biome Research Memos 72 to 76. Logan, UT: Utah State University. 71 p.

Hutchings, Selar S. 1952. Snout moth damage to shadscale in southern Idaho. National Wool Growers. July 24-25, 38.

Hutchings, Selar S. 1954. Managing winter sheep range for greater profit. Farmers Bull. 2067. Washington, DC: U.S. Department of Agriculture. 46 p.

Hutchings, Selar S.; Stewart, George. 1953. Increasing forage yields and sheep production on intermountain winter ranges. Circular 925. Washington, DC: U.S. Department of Agriculture. 63 p.

Jensen, Charles H.; Urness, Philip T. 1979. Winter cold damage to bitterbrush related to spring sheep grazing. Journal of Range Management. 32: 214-216.

Kleinkopf, G. E.; Wallace, A.; Cha, J. W. 1975. Sodium relations in desert plants: 4. Some physiological responses of Atriplex confertifolia to different levels of sodium chloride. Soil Science. 120: 45-48.

Knowlton, G. F. 1934. Lizards as a factor in the control of range insects. Journal of Economic Entomolgy. 28: 998-1004.

Knowlton, G. F.; Janes, M. T. 1932. Studies of the food habits of Utah lizards. The Ohio Journal of Science. 32: 467-470.

Knowlton, George F.; Janes, Melvin, T. 1934. Distributional and food habits notes on Utah lizards. Copia. April (1): 10-14.

Lindsey, D. L. 1984. The role of vesicular-arbuscular mycorrhizae in shrub establishment. In: Williams, S. E.; Allen, M. F., eds. VA mycorrhizae and reclamation of arid and semiarid lands. Scientific Report SA 1261. Laramie, WY: University of Wyoming, Wyoming State Agriculture Experiment Station: 52-67.

Lipschitz, Nili; Waisel, Yoav. 1982. Adaptation of plants to saline environments: salt excretion and glandular structure. In: Sen, D. N.; Rajpurohit, K. S., eds. Contributions to the ecology of halophytes. The Hague: Dr. W. Junk Publisher: 197-214.

Lunt, O. R.; Letey, J.; Clark, S. B. 1973. Oxygen requirements for root growth in three species of desert shrubs. Ecology. 54: 1356-1362.

Marks, G. C.; Kozlowski, T. T. 1973. Ectomycorrhizae: their ecology and physiology. New York, London: Academic Press. 444 p.

Marx, Donald H. 1972. Ectomycorrhizae as biological deterrents to pathogenic root infections. Annual Review of Phytopathology. 10: 429-454.

McArthur, E. Durant; Blauer, A. Clyde; Sanderson, Stewart C. 1988, Mule deer-induced mortality of mountain big sagebrush. Journal of Range Management. 41: 114-117.

McCawley, P. 1985. Preliminary findings from grasshopper damage study. Logan, UT: Utah State University, Department of Range Science. 3 p.

McKell, C. M.; Goodin, J. R.; Jeffries, R. L. 1986. Saline land of the United States of American and Canada. Reclamation and Revegetation Research. 5: 159-165.

Meadows, Roy W.; Haws, B. Austin; Monsen, Stephen B. 1984. Insect defoliation of fourwing saltbush (Atriplex canescens) in southwestern Idaho. Abstracts--37th annual meeting, Society for Range Management; 1984 February 12-17; Rapid City, SD. Abstract 025. Denver, CO: Society for Range Management.

Moore, Russell T.; Breckle, Siegmar-W.; Caldwell, Martyn M. 1972. Mineral ion composition and osmotic relations of Atriplex confertifolia and Eurotia lanata. Oecologia. 11: 67-78.

Mosse, B. 1973. Advances in the study of vesicular-arbuscular mycorrhiza. Annual Review of Phytopathology. 11: 171-196.

Nelson, D. L. 1977-1978. Laboratory data: isolation of fungi from dying shadscale in Nevada. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT.

Nelson, David L.; Krebill, Richard G. 1981. A sagebrush wilt disease of unknown cause. Great Basin Naturalist. 41: 185-191.

Nelson, David L.; Tiernan, Charles F. 1983. Winter injury of sagebrush and other wildland shrubs in the western United States. Res. Pap. INT-314. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 17 p.

Nelson, David L.; Welch, Bruce L. 1984. Basal decay of fourwing saltbush Atriplex canescens. Abstracts--37th annual meeting, Society for Range Management; 1984 February 12-17; Rapid City, SD. Abstract 268. Denver, CO: Society for Range Management.

Nerney, N. J.; Hamilton, A. G. 1969. Effects of rainfall on range forage and populations of grasshoppers, San Carlos Apache Indian Reservation, Arizona. Journal of Economic Entomology. 61: 329-333.

Norton, Don C. 1979. Relationships of physical and chemical factors to populations of plant-parasitic nematodes. Annual Review of Phytopathology. 17: 279-299.

Parker, Matthew A. 1985. Size-dependent herbivore attack and the demography of an arid grassland shrub. Ecology. 66: 850-860.

Pasternak, Dov. 1987. Salt tolerance and crop production- A comprehensive approach. Annual Review of Phytopathology. 25: 271-291.

Pechanec, J. F.; Pickford, G. D.; Stewart, George. 1937. Effects of the drought on native vegetation of the upper Snake River Plains, Idaho. Ecology. 18: 490-505.

Piemeisel, Robert L. 1951. Causes affecting change and rate of change in a vegetation of annuals in Idaho. Ecology. 32: 53-72.

Plummer, A. Perry. 1974. Morphogenesis and management of woody perennials in the United States. In: Kreitlow, Kermit W.; Hert, Richard

H., eds. Plant morphogenesis as the basis for scientific management of range resources; Proceedings: workshop of the United States-Australian rangelands panel; 1971 March 29-April 5; Berkeley, CA. Misc. Publ. 1271. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 223 p.

Powell, N. T. 1971. Interactions between nematodes and fungi in disease complexes. Annual Review of Phytopathology. 9: 253-274.

Pringle, William L. 1960. The effect of a leaf feeding beetle on big sagebrush in British Columbia. Journal of Range Management. 13: 139-142.

Richardson, Steven G.; McKell, C. M. 1980. Salt tolerance of two saltbush species grown in processed oil shale. Journal of Range Management. 33: 460-463.

Rohrbach, Kenneth G.; Beardsley, John W.; German, Thomas L.; Reimer, Neal J.; Sanford, Wallace G. 1988. Mealybug wilt, mealybugs and ants on pineapple. Plant Disease. 72: 558-565.

Schirmer, Ute; Breckle, Siegmar-W. 1982. The role of bladders for salt removal in some Chenopodiaceae (mainly Atriplex species). In: Sen, David N.; Rajpurohit, Kishan S., eds. Contributions to the ecology of halophytes. The Hague: Dr. W. Junk Publishers: 215-231.

Schoeneweiss, Donald F. 1975. Predisposition, stress, and plant disease. Annual Review of Phytopathology. 13: 193-211.

Schumaker, G. A.; Hanson, Clayton L.; Johnson, Clifton W. 1979. Loss of mountain big sagebrush (Artemisia tridentata vaseyana) stands in southwestern Idaho during the winter of 1976-77. Abstracts--32nd annual meeting, Society for Range Management; 1979 February 12-15; Casper, WY. Denver, CO: Society for Range Management. 59 p.

Shantz, H. L. 1925. Plant communities in Utah and Nevada. In: Tidestrom, I. Flora of Utah and Nevada. Contributions from the U.S. National Herbarium. No. 25. Washington, DC: Smithsonian Institution: 15-23.

Sharp, Lee A.; Sanders, Kenneth D. 1978. Rangeland resources of Idaho: a basis for development and improvement. Misc. Publ. 6, Idaho Rangeland Commission: Contribution No. 141. Moscow, ID: University of Idaho, Forest, Wildlife, and Range Experiment Station. 73 p.

Sheldon, J. K.; Rogers, L. F. 1978. Grasshopper food habits within a shrub-steppe community. Oecologia. 32: 85-92.

Slankis, V. 1974. Soil factors influencing formation of mycorrhizae. Annual Review of Phytopathology. 12: 437-457.

Smith, R. S. Jr.; Scharpf, R. F.; Schneegas, E. R. 1965. Frost injury to bitterbrush in eastern California. Res. Note PWS-82. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 4 p.

Solbrig, Otto T. 1970. Principles and methods of plant biosystematics. London: Macmillan. 226 p.

Springfield, H. W. 1966. Germination of fourwing saltbush seeds at different levels of moisture stress. Agronomy Journal. 58: 149-150.

Stebbins, G. Ledyard. 1975. Shrubs as center of adaptive radiation and evolution. In: Stutz, Howard C., ed. Symposium and workshop: wildland shrubs; Proceedings; 1975 November 6; Provo, UT: Brigham Young University: 120-140.

Stevens, Richard. 1985. [Personal communication and letter]. On file at: U.S. Department of Agriculture, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT.

Stewart, George. 1935. Plant cover and forage condition on spring-fall winter ranges, largely on public domain lands in the intermountain region. Utah Juniper. 6: 9-13.

Stewart, George, Cottam, W. P.; Hutchings, Selar S. 1940. Influence of unrestricted grazing on northern salt desert plant association in western Utah. Journal of Agricultural Research. 60: 289-316.

Stickney, Peter F. 1965. Note on winter kill of Ceanothus velutinus. Proceedings of the Montana Academy of Science. 25: 52-57.

Stutz, Howard C. 1978. Explosive evolution of perennial Atriplex in western America. In: Harper, K. T.; Reveal, James L., organizers. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs No. 2: 161-268.

Stutz, Howard C.; Sanderson, Stewart C. 1983. Evolutionary studies of Atriplex: chromosome races of A. confertifolia (shadscale). American Journal of Botany. 70: 1536-1547.

U.S. Department of Agriculture, Forest Service. 1937. Range plant handbook. Washington, DC: U.S. Department of Agriculture, Forest Service.

U.S. Department of Agriculture, Forest Service, Forest-Range Task Force. 1972. The nation's range resources--a forest-range environmental study. Forest Resources Rep. 19. Washington, DC: U.S. Department of Agriculture, Forest Service. 147 p.

U.S. Department of Interior, Bureau of Land Management. Survey, 1985-1986. Survey data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT.

Vallentine, John F. 1980. Range development and improvements. 2d ed. Provo, UT: Brigham Young University Press. 545 p.

Van Epps, Gordon A. 1975. Winter injury to fourwing saltbush. Journal of Range Management. 28: 157-159.

Wallace, A.; Romney, E. M.; Hale, V. Q. 1973. Sodium relations in desert plants: 1. Cation contents of some plant species from the Mojave and Great Basin deserts. Soil Science. 115: 284-287.

Wallner, W. E. 1987. Factors affecting insect population dynamics: differences between outbreak and non-outbreak species. Annual Review of Entomology. 32: 317-340.

Watts, J. Gordon; Huddleston, Ellis W.; Owens, John C. 1982. Rangeland entomology. Annual Review of Entomology. 27: 281-311.

West, Neil E. 1982. Dynamics of plant communities dominated by chenopod shrubs. International Journal of Ecology and Environmental Science. 8: 73-84.

West, Neil E.; Ibrahim, Kamal I. 1968. Soil-vegetation relationships in the shadscale zone of southeastern Utah. Ecology. 49: 445-456.

Whitney, E. D.; Duffus, James E., eds. 1986. Compendium of beet diseases and insects. St. Paul, MN: The American Phytopathological Society Press. 76 p.

Wilhelm, Stephen. 1965. Pythium ultimum and the soil fumigation growth response. Phytopathology. 55: 1016-1020.

Workman, John P.; West, Neil E. 1969. Ecotypic variation of Eurotia lanata populations in Utah. Botanical Gazette. 130: 26-35.

Yarwood, C. E. 1959. Predisposition. In: Horsfall, J. G.; Dimond, A. E.; eds. Plant pathology: An advanced treatise. Vol. 1. The diseased plant. New York, London: Academic Press: 521-562.

Zak, Bratislav. 1964. Role of mycorrhizae in root disease. Annual Review of Phytopathology. 2: 377-392.

ARE WILDLAND PLANT COMMUNITIES A POTENTIAL SOURCE OF UNDERSTANDING BIOLOGICAL RESPONSES TO IRON-DEFICIENCY STRESS?

Sheldon D. Nelson and Von D. Jolley

ABSTRACT: Iron deficiency is a serious problem for many cultivated crops in arid regions with predominately calcareous soils, but is rarely observed in wildland shrub-grass ecosystems. The economic importance of iron deficiency in cultivated species has motivated investigations concerning plant response to iron stress and has provided evidence for several proposed mechanisms including: (a) various combinations of increased root excretion of hydrogen ions and reductants, higher levels of chemical reduction enzymatic activities, and organic acids within the root, and changes in root morphology in Fe-stressed dicotyledenous plants; (b) release of phytosiderophores (iron chelators) by the roots of Fe-stressed graminaceous plants. The former mechanism, currently designated Strategy I, supposes a solubilization of soil iron and reduction processes to make iron available to plants. The latter mechanism, designated Strategy II, supposes an extrusion of phytosiderophores with highly selective affinities for iron to enhance uptake. In addition, hydroxamate siderophores produced by fungi and bacteria during iron-stress conditions may provide an important iron supply to roots of both plant types. The understanding of these mechanisms has been developed almost exclusively from the study of domesticated species. It has been postulated that plants could not obtain iron in arid land soils without these factors modifying iron solubility. However, virtually nothing is currently known about the factors which allow wildland species to thrive in arid soils.

INTRODUCTION

Wildland plants of arid regions have adapted to harsh biological environments in which extremes and fluctuations in temperature, moisture, salinity, radiation and nutrients are common and in which growth limiting factors due to soil physical and chemical properties are normal. Some plants thrive in soils that are droughty, calcareous, high in pH, low in organic matter and iron solubility. However, in the case of iron, little is known about the successful adaptation of a wide variety of organisms under these harsh conditions.

Iron is an essential element for plants which is most efficiently supplied through vigorous new root growth in diffusion-controlled processes. Iron availability is enhanced by low pH, adequate moisture and balanced nutrition (O'Connor and others 1971; Chaney 1984). Well-aerated alkaline soils predictably contain inadequate quantities of available iron for higher plants because high pH and unsuitable redox potentials diminish iron solubility (Lindsay 1979). Soluble inorganic iron levels in calcareous soils of at least two orders of magnitude less than the potential requirement for plants (Schwab 1981) are evidenced by iron chlorosis of many introduced cultivated crops (Nelson and others 1982). Some introduced species do not survive the induced iron stress because they lack adaptive mechanisms, whereas wildland plants seldom exhibit iron-stress chlorosis due to insufficient iron uptake. In adapted (Fe-efficient) cultivated species, iron mobilization and uptake occurs in the apical region of roots (Brown and Ambler 1973), where root-induced solubilizing and chelating processes chemically alter the rhizosphere environment. These iron-stress response mechanisms have recently been reviewed (Romheld and Marschner 1986; Wallace 1987; Brown and Jolley 1988). Although native plants have apparently developed mechanisms to allow iron uptake in a hostile environment (Brown 1977; Nelson and others 1982), virtually no understanding of the mechanisms in the native plants has been accumulated. The purpose of this paper is to review the current knowledge of iron-stress response in cultivated species and to suggest that the study of native wildland plants may hold a potential for further understanding of biological responses to iron stress.

DISCUSSION

Classification of Plant Response Mechanisms

Crop species or cultivars which grow in conditions with high potential for development of iron chlorosis (i.e. calcareous, high pH, high phosphorus, cation imbalance, or low iron) without becoming chlorotic have been classified as iron efficient. Those which do develop chlorosis under these conditions are referred to as iron inefficient. The iron-efficient cultivars have developed specific mechanisms which mobilize iron and allow its uptake, while the iron-inefficient cultivars do not. However, mobilization of iron can also be stimulated by nonspecific mechanisms. The latter mechanisms are not related to the iron nutritional status

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Sheldon D. Nelson and Von D. Jolley are Associate Professors of Agronomy, Department of Agronomy and Horticulture, Brigham Young University, Provo, UT.

nor to the Fe-efficient or Fe-inefficient nature of the plant, but to normal plant processes. Both types of mechanisms will be discussed briefly in this review.

Nonspecific Iron-Uptake Mechanisms

Plant roots excrete hydrogen ions into the bulk solution due to preferential cation uptake. This release increases iron solubility, lowers redox potential, and consequently makes iron reduction and subsequent uptake possible (Wallace and others 1968; Brown 1977; Lindsay 1979, 1984; Bienfait and others 1982a; Fleming and Foy 1982; Johnson 1982; Varanini and Maggioni 1982; Hershey and Paul 1984). The amount of hydrogen ion release is dependent on excess base/nitrogen ratio (ratio of cation to anion uptake), the form of nitrogen (ammonium or nitrate) absorbed, and the phosphorus nutritional status of the plant (Marschner and Romheld 1983; Romheld and Marschner 1986).

Organic acid extrusion into bulk soil solution by roots can potentially increase iron solubility through acidification as well as through reduction and chelation (Gardner and others 1983; Young and Terry 1984; Romheld and others 1984).

Sloughed cells and root exudates increase microbial activity in the rhizosphere, which can cause lower redox potential, acidification and improved iron uptake. Phytosiderophores exuded by higher plants become iron chelators and will be discussed under specific iron-stress response mechanisms.

Microbial production and release of chelating compounds and siderophores may have a significant impact on the iron nutrition of higher plants (Trolldenier 1973; Barber and Lee 1974; Emery 1977, 1982; Sauerbeck and others 1982; Powell and others 1982; Rodriguez and others 1984). This chelation process can increase the solubility and availability of iron to roots of higher plants (Orlando and Nielands 1982; Cline and others 1984) through the increased concentration of siderophores within the root zone (Reid and others 1984). Beneficial effects of microbial siderphore release have been demonstrated in sunflower, peanut, tomato, duckweed, sorghum and oat, but the extent and importance of this natural chelation process has yet to be quantified in the ecology of wildland plants.

Specific Iron-Stress Response Mechanisms

Strategies for Iron Uptake--Recently, two broad strategies of plant response to iron deficiency stress have been proposed (Romheld and Marschner 1986). Plants with the more complicated Strategy I mechanisms are dicots and nongramineous monocots. The iron-stress responses characteristic of Strategy I plants include: formation of rhizodermal transfer cells or increased formation of root hairs, enhanced release of hydrogen ions, release of phenolics or "reductants", increased levels of citrate in roots, and enhanced iron (III) reduction at the plasma membrane (Brown and Ambler 1973, 1974; Landsberg 1982). However, not all Fe-efficient species exhibit the full compliment of responses. Only grasses have been found to exhibit the Strategy II mechanisms in which root release of phytosiderophores results in chelation of inorganic iron (III) and subsequent transport to and absorption through the plasma membrane by a highly specific uptake system and in the absence of any iron reduction processes.

Of the two proposed strategies for responding to Fe stress, Strategy I has been most extensively studied. Because the Strategy II mechanisms have only recently been discovered, they have been less extensively studied and may seem more simplistic. In addition, Brown and Jolley (1988) suggest that it may be too early to finalize the division of plants into two simple categories. A more extensive description of the mechanisms of both Strategies follows.

Hydrogen Ion Extrusion from Modified Root Systems--Enhanced production of protons is nearly universally present in plants exhibiting the Strategy I response. This acidification is specifically invoked under Fe-deficiency stress conditions and is reportedly associated with a plasma membrane ATPase driven proton pump (Landsberg 1982). It is often associated with morphological changes of roots such as diminution of apical roots, abundant root hairs or formation of rhizodermal transfer cells. These specialized root characteristics are also the site of active iron uptake during iron stress (Wallace and others 1968; Landsberg 1982, 1984; Romheld and others 1982; Romheld and Kramer 1983).

Excretion of Reductants--Iron (III) is reduced to the more plant available form [iron (II)] when specialized "reductants" are released by plant roots during iron stress (Brown 1961, 1977; Brown and Ambler 1973; Olsen and others 1982; Wallace 1983; Hether and others 1984; Kannan and others 1984). These reductants are effective in reducing iron at low pH (4.5) and are closely associated with the other Fe-deficiency-induced changes in the roots of dicots (Camp and others 1987).

Enzymatic Iron Reduction--Iron (III) is reduced enzymatically at the outer surface of the plasmalemma of roots (Chaney and others 1972; Beinfait and others 1982a, 1982b, 1984; Barrett-Lennard and others 1983; Tipton and Thowsen 1983; Campbell and Redinaugh 1984; Sijmons and Bienfait 1984; Uren 1984; Wallace and others 1984; Camp and others 1987). This reduction is important as iron (II) is the predominate form absorbed by dicotyledenous species. This reduction is also closely linked to other parts of the Fe-stress response mechanism (Camp and others 1987).

Accumulation of Citrate in Roots--Before iron reduced at the plasmalemma is transported to the plant tops it is is oxidized [iron (III)] and complexed with citrate in the xylem. Several investigators have reported a build up of citrate and other organic acids in iron-stressed plants, and Fe-efficient cultivars contain higher levels of root citrate than Fe-inefficient cultivars (Clark and others 1973; Brown 1977).

Release of Phytosiderophores--Under conditions of iron-deficiency stress, oat, barley, and rice released iron-chelating compounds similar to those produced by microorganisms. Chelation of iron and subsequent uptake through root production of phytosiderophores is particularly active in species belonging to Gramineae, but has not been identified in dicots (Peters and Warren 1970; Takagi 1976; Nielands 1977; Raymond 1977; Takemoto and others 1978; Nomoto and others 1981; Fushiya and others 1982; Mino and others 1983; Reid and others 1984; Rodriguez and others 1984; Takagi and others 1984). Phytosiderophores of barley and oats have been characterized as the nonproteinogenic amino acids, mugineic acid and avenic acid, respectively (Fushiya and others 1982). Following the iron-stress response of increased release of photosiderophores, production of phytosiderophores declines within 24 to 48 hours when sufficient iron is supplied (Takagi and others 1984).

Uptake of iron by monocots under iron stress is presumed to be as iron (III). However, Crowley and others (1988) suggest that there are siderophore binding sites on the plasmalemma of oat root cortical cells wherein iron uptake occurs by extraction from the organic chelating molecule through enzymatic reduction of iron (III) to iron (II).

The pH (pH 4-8) does not substantially affect the production nor activity of phytosiderophores, whereas the release of reductant in non-gramineous plants is highly pH dependent and iron reduction through this process occurs much slower than phytosiderophore chelation (Takagi 1976; Romheld and Marschner 1983). Phytosiderophores are not always iron specific and chelation with copper and zinc and other elements is not uncommon, thereby influencing the release of additional essential micronutrients (Takagi 1976; Benes and others 1983).

CHALLENGE

Iron uptake mechanisms of cultivated species have been extensively studied and significant progress has been made to understand the processes involved. At best, two strategies have been identified in these crops, but an understanding of the mechanisms involved is far from complete. Wildland species seldom exhibit iron deficiency chlorosis, however one assumes that they are exposed to an adverse iron-uptake environment. To date, there is no existing evidence that the mechanisms known to function in cultivated crops even exist in wildland species. Identification and investigation of the mechanisms involved in wildland species seems critical to a complete understanding of iron nutrition in plants. Wildland species may be a valuable key in the development of new iron efficient crops and ornamental species for the vast areas of calcareous soils throughout the world.

REFERENCES

Barber, D. A.; Lee, R. B. 1974. The effect of micro-organisms on the absorption of manganese by plants. New Phytol. 73: 97-106.

Barrett-Lennard, E. G.; Marschner, H.; Romheld, V. 1983. Mechanism of short term Fe reduction by roots: Evidence against the role of secreted reductants. Plant Physiol. 73: 893-898.

Benes, I.; Schrieber, K.; Ripperger, H.; Kircheiss, A. 1983. Metal complex formation by nicotianamine, a possible phytosiderophore. Experienta. 39: 261-272.

Bienfait, H. F.; Duivenvoorden, J.; Verkerke, W. 1982a. Ferric reduction by roots of chlorotic bean plants: Indications for an enzymatic process. J. Plant Nutr. 5: 451-456.

Bienfait, H. F.; van der Bliek, A. M.; Bino, R. J. 1982b. Different regulations on ferric reduction and acidification of the medium by roots of Fe-stressed plants in a "Rhizostat". J. Plant Nutr. 5: 447-450.

Bienfait, H. F.; van den Briel, M. L.; Mesland-Mul, N. T. 1984. Measurement of the extracellular mobilizable iron pool in roots. J. Plant Nutr. 7: 659-665.

Brown, J. C. 1977. Genetically controlled chemical factors involved in absorption and transport of iron by plants. Adv. Chem. Ser. No. 161, pp. 93-103.

Brown, J. C.; Ambler, J. E. 1973. "Reductants" released by roots of Fe-deficient soybeans. Agron. J. 65: 311-324.

Brown, J. C.; Ambler, J. E. 1974. Iron-stress response in tomato (Lycopersicon esculentum). 1. Sites of Fe reduction, absorption and transport. Physiol. Plant. 31: 221-224.

Brown, J. C.; Jolley, V. D. 1988. Strategy I and Strategy II mechanisms affecting iron availability to plants may be established too narrow or limited. J. Plant Nutr. (In press).

Brown, J. C.; Holmes, R. S. Tiffin, L. O. 1961. Iron chlorosis in soybeans as related to genotype of rootstalk. 3. Chlorosis susceptibility and reductive capacity at the root. Soil Sci. 91: 127-132.

Camp, S. D.; Jolley, V. D.; Brown, J. C. 1987. Comparative evaluation of factors involved in Fe stress response in tomato and soybeans. J. Plant Nutr. 10: 423-442.

Campbell, W. H.; Redinbaugh, M. G. 1984. Ferric-citrate reductase activity of nitrate reductase and its role in iron assimilation by plants. J. Plant Nutr. 7: 799-806.

Chaney, R. L. 1984. Diagnostic practices to identify iron deficiency in high plants. J. Plant Nutr. 7: 46-47.

Chaney, R. L.; Brown, J. C.; Tiffin, L. O. 1972. Obligatory reduction of ferric chelates in iron uptake by soybeans. Plant Physiol. 50: 208-213.

Clark, R. B.; Tiffin, L. O.; Brown, J. C. 1973. Organic acids and iron translocation in maize genotypes. Plant Physiol. 52: 147-150.

Cline, G. R.; Reid, C. P. P.; Powell, P. E.; Szanizlo, P. J. 1984. Effects of a hydroxamate siderophore on iron absorption by sunflower and sorghum. Plant Physiol. 76: 36-39.

Crowley, D. E.; Reid, C. P. P.; Babbitt, M. J.; Szanizlo, P. J. 1988. Kinetics of plant iron uptake from microbial siderophores under direct-use conditions. In: Proc. 4th Inter. Symp. Iron Nutrition and Interactions in Plant. J. Plant Nutr. (In press).

Emery, T. 1977. The storage and transport of iron. In: Siegel, H. (ed.). Metal Ions in Biological Systems. Vol. 7. Iron in Model and Natural Compounds. New York: Marcel Dekker, Inc. 77-125.

Emery, T. 1982. Iron metabolism in humans and plants. Am. Scient. 70: 626-632.

Flemming, A. L.; Foy, C. D. 1982. Differential response of barley varieties to Fe stress. J. Plant Nutr. 5: 457-468.

Fushiya, S.; Takahashi, K.; Nakatsuyama, S.; Sato, Y.; Nozoe, S.; Takagi, S. 1982. Co-occurrence of nicotianamine and avenic acids in *Avena sativa* and *Oryza sativa*. Phytochemistry. 21: 1907-1908.

Gardner, W. K.; Barber, D. A.; Parbery, D. G. 1983. The acquisition of phosphorus by *Lupinus albus* L. III. The probable mechanism by which phosphorus movement in the soil/root interface is enhanced. Plant Soil. 70: 107-124.

Hershey, D. R.; Paul, J. L. 1984. Iron nutrition of the broadleaf evergreen shrub, *Euonymus japonica* Thub. J. Plant Nutr. 7: 641-657.

Hether, N. H.; Olsen, R. A.; Jackson, L. L. 1984. Chemical identification of iron reductants exuded by plant roots. J. Plant Nutr. 7: 667-676.

Johnson, G. V. 1982. Application of high performance liquid chromatography in the characterization of iron stress response. J. Plant Nutr. 5: 499-514.

Kannan, S. 1984. Studies on Fe deficiency stress response in three cultivars of sunflower (*Helianthus annus* L.) J. Plant Nutr. 7: 1203-1212.

Landsberg, E. -Ch. 1982. Transfer cell formation in the root epidermis. A prerequisite for Fe efficiency? J. Plant Nutr. 5: 415-432.

Landsberg, E. -Ch. 1984. Regulation of iron-stress-response by whole-plant activity. J. Plant Nutr. 5: 821-840.

Lindsay, W. L. 1979. Chemical equilibria in soils. New York: John Wiley & Sons.

Lindsay, W. L. 1984. Soil and plant relationships associated with iron deficiency with emphasis on nutrient interactions. J. Plant Nutr. 7: 489-500.

Marschner, H.; Romheld, V. 1983. *In vitro* measurement of root-induced pH changes at the soil-root interface: Effect of plant species and nitrogen source. Z. Pflanzen Physio. III: 241-251.

Mino, Y; Ishida, T.; Ota, N.; Inoue, K.; Nomoto, T. K.; Takemoto, H.; Tanaka, M.; Sugiura, Y. 1983. Mugineic acid-iron (III) complex and its structurally analogous cobalt (III) complex: Characterization and implication for absorption and transport or iron in gramineous plants. J. Am. Chem. Soc. 105: 4671-4676.

Nelson, S. D.; Wallace, A.; Brown, J. C.; Miller, G. W.; Lindsay, W. L.; Jolley, V. D. (eds.). 1982. Proceedings of 1st International Symposium on Iron Nutrition and Interactions in Plants. J. Plant Nutr. 5: 229-1001.

Nielands, J. B. 1977. Siderophores: biochemical ecology and mechanism of iron transport in enterobacteria. Adv. Chem. Ser. 162: 3-32.

Nomoto, K.; Yoshioka, Y.; Arima, M.; Fushiya, S.; Takagi, S.; Takemoto, T. 1981. Structure of 2-deoxymugineic acid, a novel amino acid possessing iron-chelating activity. Chimia 35: 249-250.

O'Connor, G. A.; Lindsay, W. L.; Olsen, S. R. 1971. Diffusion of iron and iron chelates in soil. Soil Sci. Soc. Amer. Proc. 35: 407-410.

Olsen, R. A.; Brown, J. C.; Bennett, J. H.; Blume, D. 1982. Reduction of Fe as it relates to Fe chlorosis. J. Plant Nutr. 5: 433-445.

Orlando, J. A.; Neilands, J. B. 1982. Ferrichrome compounds as a source of iron for higher plants. In: Kehl, H. ed. Chemistry and Biological Activities of Hydroxamic Acids; Basel: Karger.

Peters, W. J.; Warren, R. A. J. 1970. The mechanism of iron uptake in *Bacillus subtilus*. Can. J. Microbiol. 16: 1285-1291.

Powell, P. E.; Staniszlo, P. J.; Cline, G. R.; Reid, C. P. 1982. Hydroxamate siderophores in the iron nutrition of plants. J. Plant Nutr. 5: 653-673.

Raymond, K. N. 1977. Kinetically inert complexes of the siderophores in studies of microbial iron transport. Adv. Chem. Ser. 162: 33-53.

Reid, C. P. D.; Crowley, D. E.; Kim, H. J.; Powell, P. E.; and Szaniszlo, P. J. 1984. Utilization of iron by oat when supplied as ferrated synthetic chelate or as ferrated hydroxamate siderophore. J. Plant Nutr. 7: 437-447.

Rodriguez, R. K.; Klemm, D. J.; Barton, L. L. 1984. Iron metabolism by an ectomycorrhizal fungus Enoocum graniforme. J. Plant Nutr. 7: 459-468.

Romheld, V.; Kramer, V. 1983. Relationship between proton efflux and rhizodermal transfer cells induced by iron deficiency. Z. Pflanzenphysiol 113: 73-83.

Romheld, V.; Marschner, H.; Kramer, D. 1982. Response to Fe deficiency in roots of "Fe-efficient" plant species. J. Plant Nutr. 5: 489-498.

Romheld, V.; Marschner, H. 1986. Mobilization of iron in the rhizosphere of different plant species. In: Tinker and Lauchli, eds. Advances in Plant Nutrition, Vol. 2 Chap. 5. New York: Praeger Publishers: 155-197.

Romheld, V.; Muller, C.; Marschner, H. 1984. Localization and capacity of proton pumps in roots of intact sunflower plants. Plant Physiol. 76: 603-606.

Sauerbeck, D.; Nonnen, S.; Allard, J. L. 1981. Consumption and turnover of photosynthates in the rhizosphere depending on plant species and growth conditions. Landw. Forschung Sonderheft 37: 207-216.

Schwab, A. P. 1981. Stability of Fe chelates and the availability of Fe and Mn to plants as affected by redox. Ft. Collins, CO: Colorado State University. 157 p.

Sijmons, P. C.; Bienfait, H. F. 1984. Mechanism of iron reduction by roots of Phaseolus vulgaris L. J. Plant Nutr. 7: 687-693.

Takagi, S. 1976. Naturally occurring iron-chelating compounds in oat and rice root washings. Soil Sci. Plant Nutr. 22: 423-433.

Takagi, S.; Nomoto, K.; Takemoto, T. 1984. Physiological aspect of mugineic acid, a possible phytosiderophore of gramineaceous plants. J. Plant Nutr. 7: 469-477.

Takemoto, T.; Nomoto, K.; Fushiya, S.; Ouchi, R.; Kusano, G.; Hikino, H.; Takagi, S.; Matuura, Y.; Kakudo, M. 1978. Structure of mugineic acid, a new amino acid possessing an iron-chelating activity from root washings of water-cultured Hordeum vulgare L. Proc. Jpn. Aca. Ser. B, 54: 469-473.

Tipton, C. L.; Thowsen, J. 1983. Reduction of iron by soybean roots: Correlation with iron deficiency on calcareous soils. Iowa State J. Res. 57: 409-422.

Trolldenier, G. 1973. Secondary effects of potassium and nitrogen nutrition of rice: Change in microbial activity and iron reduction in the rhizophere. Plant Soil. 38: 267-279.

Uren, N. C. 1984. Forms, reactions and availability of iron in soils. J. Plant Nutr. 7: 165-176.

Varanini, Z.; Maggioni, A. 1982. Iron reduction and uptake by grapevine roots. J. Plant Nutr. 5: 521-529.

Wallace, A. 1983. Root membrane potentials, obligatory need for reduction of Fe, excess chelating agents and pe + pH. J. Plant Nutr. 6: 531-536.

Wallace, A. 1987. Root-soil interface mechanisms which provide the adaptability of plant species to arid calcareous soils and some effects of stress on those mechanisms. In: Wurtele, M. J. and Berkofsky, L., eds. Progress in Desert Research. (Totowa, N. J.: Rowman and Allanheld: in press).

Wallace, A.; Frolich, E.; El. Gazzar, A. 1968. Some effects of iron deficiency on ion uptake and root excretion to tobacco. In: International Atomic Energy Symposium on isotopes and radiation in soil organic-matter studies: Proceedings; 1968 July 15-19; Vienna. Int. Atomic Energy Agency: 385-396.

Wallace, A.; Mueller, R. T. 1978. Complete neutralization of a portion of calcareous soil as a means of preventing iron chlorosis. Agron. J. 70: 888-890.

Wallace, A.; Wallace, G. A.; Wood, R. A.; Abou-Zamzam, A. M. 1984. Uptake by plants of iron from iron chelates. J. Plant Nutr. 7: 695-698.

Young, T. F.; Terry, N. 1984. Specificity of iron transport in iron-stressed sugar beet plants: Evidence for preferential accumulation of cobalt in the presence of iron. Can. J. Bot. 62: 207-210.

EFFECTS OF HEAVY GRAZING BY MULE DEER ON 'HOBBLE CREEK' MOUNTAIN BIG SAGEBRUSH SEED STALK PRODUCTION

Ronald L. Rodriguez and Bruce L. Welch

ABSTRACT: On 'Hobble Creek' mountain big sagebrush (Artemisia tridentata ssp. vaseyana) native range there is a recruitment problem. One factor contributing to this problem could be a dramatic reduction in seed production due to continuous heavy grazing (utilization of 70 percent or more of current year's growth) by wintering mule deer (Odocoileus hemionus hemionus). A deer-proof exclosure was constructed on the native site to test the effects of heavy grazing on productivity as measured by length of current year's growth, length of seed stalks, and number of seed stalks per plant. Productivity was not significantly different between grazed and nongrazed plants (13.9±2.2 vs 12.9±2.1 cm). Seed stalks of nongrazed plants were significantly longer than those of grazed plants (26.6±1.2 vs 15.8±3.5 cm). Nongrazed 'Hobble Creek' plants produced not only significantly longer seed stalks but greater numbers of seed stalks per plant than grazed plants (172.4 vs 6.1 seed stalks). A dramatic reduction of seed numbers could be one factor responsible for lack of recruitment on the native site.

INTRODUCTION

'Hobble Creek' mountain big sagebrush (Artemisia tridentata ssp. vaseyana) is a superior selection that can increase the nutritive content of the winter diet of mule deer (Odocoileus hemionus hemionus) and domestic sheep (Ovis aries) (Welch and McArthur 1979; Welch and others 1987). This selection of big sagebrush has higher amounts of winter crude protein, phosphorus, carotene, and higher in vitro digestibility than other species of shrubs, grasses, or forbs (Bunderson and others 1986; Welch and others 1986). As a big sagebrush it is slightly below average for these nutrients but is preferred over other selections by wintering mule deer and ranks among the most preferred by wintering domestic sheep. 'Hobble Creek' was released (1987), as the first superior selection of big sagebrush, as a forage plant on mule deer and domestic sheep winter ranges (Welch and others 1986).

A problem observed on 'Hobble Creek' native range is the lack of seedlings or young plants (5 years old or less). We believe this lack of recruitment is due to one or more factors: 1) killing of seedlings and young plants due to heavy grazing, 2) grass understory competition not allowing seedling establishment, and 3) reduced seed production due to heavy grazing. Heavy grazing is defined as utilization of 70 percent or more of current year's growth. The last factor, reduction of seed production, is the subject of this study. Factors 1 and 2 are being studied by other researchers.

Reduced seed production means fewer opportunities for seedling establishment. An indicator of reduced seed production would be reduction in the numbers and length of seed stalks produced per plant. A single big sagebrush seed stalk can produce several thousand seeds (McArthur and others 1979; Welch and McArthur 1979). The hypothesis tested was that nongrazed 'Hobble Creek' big sagebrush plants produce greater numbers of seed stalks and longer seed stalks than heavily grazed plants. We also tested the hypothesis that nongrazed plant productivity measured in terms of length of current year's growth would be greater than heavily grazed plants.

MATERIALS AND METHODS

On the 'Hobble Creek' big sagebrush native range, a deer-proof exclosure 100 by 50 by 8 ft (30.48 by 15.24 by 2.44 m) was constructed to provide nongrazed plants. The location of the exclosure is about 2 miles (3.2 km) east of Springville, UT, at the mouth of Hobble Creek Canyon (section 36, R3E, T7S). Plants outside the exclosure receive use on better than 70 percent of current year's growth by wintering mule deer.

A 200-ft (60.96 m) line transect was established through the middle of the exclosure. The line extended 50 ft (15.24 m) beyond either side of the 100-ft exclosure. Along this transect, 10 nongrazed and 10 grazed plants were selected for measurements. The 20 plants were chosen by starting at the east point of the transect and tagging with a metal numbered tag every third plant until 10 grazed and 10 nongrazed plants had been tagged.

Plant measurements were taken during mid-November of 1984 and 1985 and were expressed as length of vegetational current year's growth, length of seed stalks, and number of seed stalks per plant. Length of vegetative current year's growth was determined by measuring 15 leaders per plant. Randomly selected leaders were

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Ronald L. Rodriguez is soil conservationist and Bruce L. Welch is principal research plant physiologist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

measured from the terminal leaf bud scars to the tip of the terminal leaves. The 15 measurements were pooled together for a plant mean. Length of seed stalk was determined by measuring 15 or, in the case of most grazed plants all, seed stalks. The seed stalks were measured from the terminal leaf bud scars to the tip of the seed stalk. Where possible, seed stalks were selected at random over the entire crown of the plants. All measurements per plant were pooled together for a plant mean. Measurements were taken during mid-November of 1984. The third measurement, number of seed stalks, was a simple counting procedure. Seed stalk counting was done during mid-November of 1984 and 1985.

Statistical analysis performed was a one-way analysis of variance to detect differences between grazed and nongrazed plants (in some cases used to detect differences between year for grazed or nongrazed plants). We used the Minitab Statistical package (Ryan and others 1976) and significance was set at P=0.05.

RESULTS AND DISCUSSION

Results of the length of current year's growth analysis are given in table 1. Due to the lack of significant effects due to years the 2 years of data were pooled. Nongrazed plants (13.9 cm) were not significantly longer than grazed plants (12.9 cm). This observation is in agreement with a study conducted by Wright (1970). Wright found that an 80-percent clipping treatment during the winter months of December and January did not significantly reduce yields. However, Cook and Stoddart (1960) reported that a 50-percent clipping treatment applied about March 1 reduced plant vigor. Garrison (1953) reported that a 10 percent clipping treatment during winter actually increased the length of current year's growth for antelope bitterbrush (Purshia tridentata), snowbrush ceanothus (Ceanothus velutinus), rubber rabbitbrush (Chrysothamnus nauseosus), and creambush rock spirea (Holodiscus discolor). He went on to make two observations: first, that continued 100-percent clippings after about 5 years decreased plant vigor and, second; seed production was greatly reduced in direct response to clippings. Based on our observations, and those cited, heavy grazing on 'Hobble Creek' big sagebrush does not reduce the length of current year's growth but over a period of time could cause reduced vigor and increased branch mortality resulting, in time, in entire plant death.

Table 1--Comparison between mean length of current year's growth of grazed and ungrazed 'Hobble Creek' mountain big sagebrush (Artemisia tridentata ssp. vaseyana). Means are a 2-year average. Data expressed as centimeters of growth

Plant #	Grazed (cm)	Nongrazed (cm)
1	12.9	14.2
2	12.1	15.7
3	14.3	12.5
4	10.5	13.1
5	11.7	15.5
6	14.7	13.5
7	12.4	13.1
8	12.7	13.3
9	13.2	12.9
10	14.4	15.2
Mean	[1] 12.9±2.1	[1] 13.9±2.2

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[1] Means are not significantly different at the 5-percent level.

Comparisons of the length of seed stalks are given in table 2. Nongrazed plant seed stalks were significantly longer than those of grazed plants (15.8 vs 26.6 cm). This suggests that nongrazed plants with equal numbers of seed stalks would probably produce more seeds because of greater length of seed stalks.

Table 2--Mean lengths of seed stalks of grazed and ungrazed 'Hobble Creek' mountain big sagebrush plants (Artemisia tridentata ssp. vaseyana). Data are expressed as a mean of 15 measurements per plant. Measurements are given in centimeters

Plant #	Grazed	Nongrazed
1	12.0	25.4
2	14.7	25.5
3	0	25.2
4	22.5	27.2
5	18.5	26.6
6	22.0	26.5
7	23.0	26.5
8	24.5	28.1
9	20.4	26.8
10	0	28.3
Mean	[1] 15.8 ±3.5	[1] 26.6 ±1.2

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[1] Means of 1984 and 1985 growth. Means are significantly different at the 5-percent level.

The number of seed stalks are compared in table 3. Because of significant differences between years for nongrazed plants, years were not pooled. Nongrazed plants produced significantly more seed stalks (116.8-1984, 228.0-1985) than grazed plants (6.1-1984, 6.2-1985). These observations do not agree with the findings of Cook and Stoddart (1960). They reported significant reduction in number of seed stalks for 50-percent clipped plants in only 1 year of a 3-year study. Their magnitude of difference in the significant year was 32.5 seed stalks while our magnitude was 110.8 for 1984 and 222.6 for 1985. Unfortunately, we do not know what subspecies Cook and Stoddart (1960) were studying or the grazing history of the plant. Our plants had been heavily grazed (70 percent or more) for at least 5 years prior to beginning this study.

Table 3--Comparison between number of seed stalks of 1984 and 1985 grazed and 1984 and 1985 nongrazed 'Hobble Creek' mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) plants

Plant #	1984 Grazed # of seed stalks	1984 Nongrazed # of seed stalks
1	1	182
2	6	33
3	0	122
4	10	77
5	6	61
6	8	157
7	2	172
8	2	81
9	26	126
10	0	157
Mean	[1]6.1±7.8	[1]116.8±51.3
	1985 Grazed	1985 Nongrazed
1	1	389
2	7	108
3	8	207
4	10	256
5	55	189
6	10	210
7	2	226
8	0	236
9	18	198
10	1	261
Mean	[1]6.2±5.6	[1]228.0±71.0
Two-year means	6.1±6.6	172.4±83.0

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[1] Means are significantly different at the 5-percent level. Two-year means not statistically tested due to significant year effects for nongrazed plants.

Under the conditions of our study, we believe that one factor that is contributing to the lack of recruitment on the 'Hobble Creek' big sagebrush native site is a dramatic reduction in seed numbers due to heavy grazing.

REFERENCES

Bunderson, E. D.; Welch, B. L.; Weber, D. L. 1986. *In vitro* digestibility of *Juniperus osteosperma* (Torr.) Little from 17 Utah sites. Forest Science. 32: 834-839.

Cook, C. W.; Stoddart, L. A. 1960. Physiological responses of big sagebrush to different types of herbage removal. Journal of Range Management. 13: 14-16.

Garrison, G. A. 1953. Effects of clipping on some range shrubs. Journal Range Management. 303-317.

McArthur, E. D.; Blauer, A. C.; Plummer, A. P.; Stevens, R. 1979. Characteristics and hybridization of important intermountain shrubs. II. Sunflower family. Res. Pap. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

Ryan, T. A., Jr.; Joiner, B. L.; Ryan, B. F. 1976. Minitab student handbook. Boston, MA: Duxbury Press. 341 p.

Welch, B. L.; McArthur, E. D. 1979. Feasibility of improving big sagebrush (*Artemisia tridentata*) for use on mule deer winter ranges. In: Goodin, J. R.; Northington, D. K., eds. Proceedings of the international arid land conference on plant resources; 1978 October 8-15; Lubbock, TX. Lubbock, TX: Texas Tech University, International Center for Arid and Semi-Arid Land Studies:451-473.

Welch, B. L.; McArthur, E. D.; Nelson, D. L.; Pedersen, J. C.; Davis, J. N. 1986. Hobble Creek--A superior selection of low-elevation mountain big sagebrush. Res. Pap. INT-370. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Welch, B. L.; McArthur, E. D.; Rodriguez, R. L. 1987. Variation in utilization of big sagebrush accessions by wintering sheep. Journal of Range Management. 40: 113-115.

Wright, H. A. 1970. Response of big sagebrush and three-tip sagebrush to season of clipping. Journal of Range Management. 23: 20-22.

INTERACTION OF STRESSES IN THE BEHAVIOR OF NATIVE SHRUB POPULATIONS

Arthur Wallace

ABSTRACT: The vegetation of arid lands faces severe stresses of many kinds and under natural conditions. Even though shrubs are reasonably adapted to the stress conditions, they are affected by the stresses. Ordinarily, adapted plants can tolerate degrees of the stresses, but are limited with increasing levels of stresses. Of extreme importance for increasing multiple stresses is that there is much evidence that sequential additivity and even synergism operate for the multiple stresses. Natural stresses that are common to arid lands include heat, drought, wind, salinity, floods, infertile soil, and animal pressure. The addition of man-induced stresses can be devastating if sequential additivity is operating because the effects of stresses are then multiplied. Examples of multiple stresses are that shrubs may be more subject to ionizing radiation if they are simultaneously stressed with drought or with other natural stresses, or acid rain may be more damaging to a waterlogged area than to a nonwaterlogged area, or that toxic levels of more than one trace element simultaneously may be more damaging than one trace element in excess. Although many stresses can be sequentially additive, this is not always the case.

INTRODUCTION

It is well recognized that arid-land ecosystems are extremely fragile and that many uses of them by man lead to their deterioration (Anonymous 1980). Expanding deserts or desertification has been a serious worldwide problem, and in recent decades there have been attempts to control desertification (Anonymous 1980; Norman 1987). Efforts, however, have resulted in little success, and it is reported that "an overwhelming majority of anti-desertification projects would promote desertification" (Norman 1987).

Such problems are of considerable concern to those who manage wild shrub communities in arid lands. Disturbed communities recover very slowly. Those persons involved in land revegetation realize that it is much more complex than merely planting seeds or placing transplants. Multi-components of the ecosystem may need to be restored, especially those related to symbiosis (Wallace and others 1980).

REASONS FOR FRAGILITY OF ARID LAND ECOSYSTEMS

In recent years it has been becoming apparent that one of the central principles of biology is the interacting nature of environmental forces, including the availability of resources that organisms require which originate in the environment. It is a general rule that the environmental factors can interact sequentially additivily or positively or negatively synergistically (Berry and Wallace 1981; Putman and Penner 1974). Interactions like this are common in agriculture (Anonymous 1974; Fjell and other 1984; Wallace and others 1981a). Arid ecosystems naturally have several different harsh components, and survival of organisms in such areas requires special adaptations. Even with the adaptations, the situation is very borderline or fragile for plant survival under such conditions (Wallace 1987).

Arid ecosystems by definition are in areas having low amounts of rainfall. Low amounts of rainfall can differ with multiple possibilities. There can be varying degrees of infrequency. Seasonality makes large differences in the ability of the rain water to sustain a system. Volume and intensity of rain with associated runoff or run-in are important parameters. Runoff can be associated with soil erosion.

Arid-ecosystems in varying degrees are usually also associated with hot climate. Because of hot climate and low amounts of vegetation, soil is poorly developed, nutrient poor, and shallow. Because of low rainfall, arid soils are usually highly calcareous. Restricted soil-forming processes, enhanced by low rainfall and small amounts of vegetation, limit removal of calcium carbonate from soil. Because soils are poorly leached and subject more to chemical degradration than to biological degradation, large quantities of soluble salts, including sodium chloride, are often present.

Shallow soils almost devoid of soil organic matter are easily eroded by water and wind. An associated sparse vegetation can lead to a degree of stability. However, if destroyed or replaced by a different vegetation which may be subject to some of the stresses listed above, the shallow soil may erode away.

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Arthur Wallace is Research Plant Physiologist, Laboratory of Biomedical and Environmental Sciences, University of California at Los Angeles, 900 Veteran Avenue, Los Angeles, CA 90024-1786, operated for the U.S. Department of Energy by the University of California under contract No. DE-AC03-76-SF00012.

MAN-MADE STRESSES IN ARID LAND ECOSYSTEMS

There are a number of man's operations that add stresses to arid-land ecosystems.

Overgrazing

This is perhaps the most common man-made stress that adds to the instability of arid lands. It has been a problem for many millenia. Overgrazed lands recover only very slowly.

Scraping or Bulldozing

Construction results in considerable destruction of native arid lands. Sometimes a bladed area is needed for temporary activities. Lands are then abandoned to erode or to remain unvegetated for a long period of time.

Water Diversion

Owens Valley in California is a well-known example of water diversion. The Los Angeles aquaduct carries water from the valley to the City of Los Angeles some 500 km away. In the past 80 years, the usual flow of water into the native shrub ecosystem has been decreased with the resulting added stress.

Agriculture

Shrub ecosystems in arid lands are constantly being replaced with irrigated agriculture. A scenario on how such land reclamation can increase the instability of arid lands has been presented (Wallace 1988).

Differential Shrub Removal

Herbicides and mechanical equipment have been used to differentially remove some shrub species from native ecosystems. The reason is to enhance growth of other plants in the ecosystems. This could relieve one kind of stress and cause others.

Off-Road Vehicle Use

Tire tracks and temporary roads in arid lands do result in erosion and other types of degradation.

Mining

Mining activities result in many different types of impacts on arid lands, including many of those listed above. Additional stresses may come from the chemical nature of material being mined, especially trace elements (Wallace and others 1981b).

SEQUENTIAL ADDITIVITY AND SYNERGISM

If stress "a" decreased biological activity by 20% and stress "b" decreased it by 40% when applied separately, the combined biological activity for both together may be 48% or a 52% decrease. The result would be a sequentially additive interaction (Berry and Wallace 1981). Such interactions imply that $\frac{(100-20\%)}{100} \times \frac{(100-40\%)}{100} = \frac{48\%}{100}$. If the biological activity for the combination were decreased by significantly more than 52%, the interaction is synergism (table 1). A decrease of significantly less than 52% would indicate a positive interaction (table 1). If, however, the combination of "a + b" increased rather than decreased the biological activity, the result is a negative synergism. Figure 1 further describes the nature of interactions. Only one level of stress "b" is used.

In table 1 it is shown that when the actual/predicted ratio is 1.00, an interaction is additive. Positive interactions would give values slightly below 1.00, and negative interactions would give values slightly above 1.00. Positive synergism would give values much less than 1.00, and negative synergism would give values well over 1.00. There could be complications if a and b have the same biological action.

The data of table 1 indicate the type of experiments needed to determine the type of interaction that may result from two or more stresses. Each pair or group of stresses must be handled separately for a given system, and the effect of each stress individually must be known in order to assess the nature of an interaction.

The most common type of interaction encountered for multiple stresses is the sequentially additive (Berry and Wallace 1981). These effects constitute a threat to the stability of arid ecosystems. For example, if five different stresses each decreased biological activity in an arid ecosystem by 50%, the combined effect could result in a final activity of only 3% if all interactions were sequentially additive. The activity could be even less if positive synergism came into play.

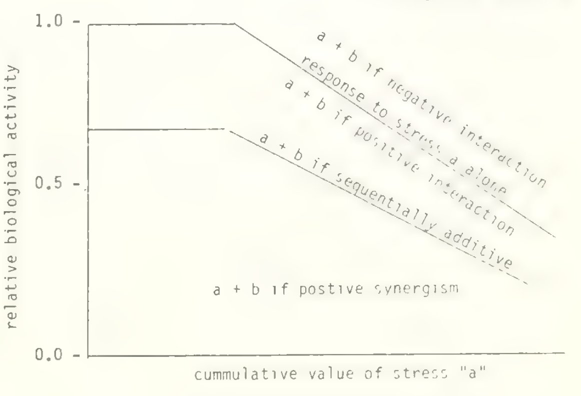

Figure 1--Possible interactions for two stresses ("a" and "b") acting simultaneously.

Table 1--Some possible responses on plants when two different stresses (a and b) interact simultaneously

Stresses	Relative growth or reproduction	Comments	Actual/predicted ratio
Situation 1--Response individually to only one of the stresses			
Control or no stress	1.00	--	--
a	1.00	no change	--
b	0.50	large decrease	--
a + b	0.50	expected if there are no interactions, the predicted or the additive value	1.00 or 0.50 ÷ 0.50[1]
a + b	1.25	negative synergism (antagonistic)	2.50 or 1.25 ÷ 0.50
a + b	0.40	postive interaction	0.80 or 0.40 ÷ 0.50
a + b	0.60	negative interaction	1.20 or 0.60 ÷ 0.50
a + b	0.25	postive synergism	0.50 or 0.25 ÷ 0.50
Situation 2--Responses individually to both the stresses			
Control or no stress	1.00	--	--
a	0.60	large decrease	--
b	0.60	large decrease	--
a + b	0.60	this would be the result if a and b each had the same effect and if 0.60 were the maximum response possible; neutral or no interaction	1.67 or 0.60 ÷ 0.36[1]
a + b	0.36	fully additive; the interaction predicted	1.00 or 0.36 ÷ 0.36
a + b	0.55	negative interaction	1.53 or 0.55 ÷ 0.36
a + b	0.30	positive interaction	0.83 or 0.30 ÷ 0.36
a + b	0.15	positive synergism	0.42 or 0.15 ÷ 0.36
a + b	0.80	negative synergism (antagonistic)	2.22 or 0.80 ÷ 0.36

[1] The 0.50 and 0.36 are the products of a x b each acting individually.

REFERENCES

Anonymous. 1974. A hungry world: The challenge to agriculture. General Report of University of California Food Task Force, Div. Agric. Sci., University of California.

Anonymous. 1980. Desertification in the U.S.: Status and issues. U.S. Dept. of Interior.

Berry, Wade L.; Wallace, Arthur. 1981. Toxicity: The concept and relationship to the dose-response curve. Journal of Plant Nutrition 3: 13-19.

Fjell, D. L.; Paulsen, G. M.; Walter, T. L.; Lawless, J. R. 1984. Nitrogen and phosphorus requirement of different wheat plant types under dryland and irrigated conditions. Journal of Plant Nutrition 7: 1289-1302.

Norman, C. 1987. Expanding deserts, shrinking resources. Science 235: 963.

Putnam, A. W.; Penner, D. 1974. Pesticide Interaction in higher plants. Residue Reviews 50: 73-106.

Wallace, Arthur. 1987. The additive and synergistic nature of multiple stresses in the stability of desert ecosystems. In: Berkofsky, Louis; Wurtele, Morton G., eds. Progress in Desert Research. Totowa, NJ; Rowman and Littlefield Publishers. 194-197 p.

Wallace, Arthur. 1988. Estimating the potential for increased desertification with reclamation of arid lands. (In press.)

Wallace, Arthur; Berry, Wade L.; Alexander, George V. 1981a. Iron, nitrogen, and phosphorus interactions in two cultivars of soybeans grown in calcareous soil. Journal of Plant Nutrition 3: 625-635.

Wallace, Arthur; Romney, Evan M.; Alexander, George V. 1981b. Multiple trace-element toxicities in plants. Journal of Plant Nutrition 3: 257-263.

Wallace, Arthur; Romney, Evan M.; Hunter, Richard B. 1980. The challenge of a desert: Revegetation of disturbed desert lands. Great Basin Naturalist Memoirs 4: 216-225.

SEED GERMINATION BIOLOGY OF ANTELOPE BITTERBRUSH (PURSHIA TRIDENTATA)

Susan E. Meyer and Stephen B. Monsen

ABSTRACT: Dormancy-breaking experiments with seeds from 28 antelope bitterbrush populations revealed no clear relationships between the degree of dormancy of recently harvested seeds and habitat characteristics at the site of seed collection. Afterripening in dry storage shortened the chilling requirement for germination, while interruption of prechill with a warm, moist period lengthened the chilling requirement. Postdispersal conditions for this summer-ripening species may have an important effect on the degree of seed dormancy at the initiation of field chilling and thus on chilling requirements and subsequent germination date.

INTRODUCTION

Antelope bitterbrush (*Purshia tridentata*) is widely distributed in the western United States and is an important component of the diet of mule deer and other native ungulates (Giunta and others 1978). Because of its importance in restoring depleted wildlife habitat through artificial seeding, antelope bitterbrush is one of the most intensively studied of all wildland shrubs (Basile 1967; Tiedemann and Johnson 1983). Its seed production and dispersal, germination, and seedling establishment ecology have been the subject of numerous studies (Evans and Young 1977; Ferguson 1962; Holmgren 1956; Hormay 1943; Shaw and Monsen 1983).

Antelope bitterbrush seed is dormant at the time of dispersal in early to midsummer and requires a period of moist chilling to germinate (Young and Evans 1976, 1981). Under field conditions, seeds apparently germinate in early spring, at a time when adequate soil moisture for successful establishment coincides with reduced risk of frost to the newly emerged seedlings (Ferguson 1972; Nord 1965).

Antelope bitterbrush seeds are quite large (mean weight of 100 seeds=2.95 g, n=28), and the chances for successful establishment of surface-lying seeds are poor. Moreover, the conditions necessary for breaking dormancy are not likely to persist for long enough on the surface, except possibly under snowpack. Artificial seeding techniques that do not include provision for seed burial are rarely successful (Basile and Holmgren 1957). Under natural conditions, seeds are often cached by rodents, and emergence takes place from cached seeds (Evans and others 1983; Sanderson 1962; Sherman and Chilcote 1972; West 1968).

The timing of antelope bitterbrush seed development is affected by site conditions, with populations on hotter, drier sites maturing seed first. The seeds on an individual plant and even within a population tend to mature synchronously. When accessions from a range of habitats are grown in a common garden, between-accession differences in seed maturation dates are much less than would be encountered in the original wild populations (Shaw and Monsen 1983).

Antelope bitterbrush is important over a wide range of habitats, from sagebrush-grass steppe vegetation where annual precipitation is less than 200 mm to lodgepole and ponderosa pine forests where annual precipitation may exceed 800 mm (Nord 1965). The average length of time between seed dispersal and the initiation of a moist chill period varies according to habitat, as does the length of the moist chill period and the optimum date for seedling emergence in spring. Antelope bitterbrush seeds collected from different habitats would thus be expected to exhibit differences in seed germination response.

Previous efforts to correlate between-source differences in germination response with habitat characteristics have been successful for rubber rabbitbrush (*Chrysothamnus nauseosus*) and big sagebrush (*Artemisia tridentata*), both autumn-ripening species with little seed dormancy (McArthur and others 1987; Meyer and Monsen in preparation). Similar efforts with antelope bitterbrush have not yielded clear patterns (Meyer and others 1987a, 1987b).

ANTELOPE BITTERBRUSH SEED DORMANCY

Bitterbrush seeds have a short chilling requirement compared with seeds of other woody Rosaceae (Schopmeyer 1974). A prechill of 4-6 weeks at 2-5 °C will break dormancy in seeds from most sources (McConnell 1960; McHenry and Jensen 1967; Meyer and others 1986, 1987b; Young and Evans 1976). The required period is shortened with increasing temperature up to 5 °C; higher temperatures are largely ineffective with no dormancy-breaking effect at 10 °C (Young and Evans 1976).

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Susan E. Meyer and Stephen B. Monsen are Ecologist and Botanist, Shrub Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

Unlike seeds of many of its rosaceous relatives, antelope bitterbrush seeds exhibit virtually no embryo dormancy. Embryos are easily excised from imbibed seeds and germinate readily and normally as long as moisture is not limiting and the embryos are kept in darkness (Hormay 1943; Meyer unpublished data; Nord 1956). This implies that the dormancy of intact seeds is somehow imposed by the thick, fibrous testa and/or the membranous endosperm.

The role of the testa or seed coat in imposing dormancy does not involve any barrier to the entry of water; seeds imbibe fully in a few hours. A possible effect of the coat is to restrict the entry of oxygen. Young and Evans (1976) invoked the oxygen-trap theory of the French physiologists Côme and Tissaoui (1973) in explaining the bitterbrush seed coat effect. They speculated that the coat might contain phenolic compounds with a high affinity for oxygen. Under warm, moist conditions, the enzymatically regulated oxygen-trapping system would combine with the low solubility of oxygen in warm water to severely limit oxygen flux to the embryo. Under moist chilling conditions, the trapping system would operate more slowly, while more oxygen would be initially dissolved in the water, so that the net oxygen flux to the embryo would be increased.

For an oxygen-trapping mechanism to impose dormancy effectively, the embryo must have an oxygen requirement in excess of that necessary for germination of a nondormant embryo. This is because nondormant embryos in general have very low oxygen requirements for germination, requirements that could be satisfied even with the trapping mechanism in place (Bewley and Black 1982; Edwards 1973). In work with charlock, an embryo-level inhibitor whose build-up was promoted by low oxygen levels was postulated to explain a similar effect (Edwards 1968, 1969).

The presence of both a chemical inhibitor and potentially oxidizable phenolic compounds has been demonstrated in seeds of antelope bitterbrush (Dreyer and Trousdale 1978). The extract containing the chemical inhibitor, which was not successfully identified, gradually lost its inhibitory activity when exposed to air. This suggests that it could be deactivated much more quickly through enzyme-mediated oxidation reactions in the embryo under conditions of adequate oxygen supply. Unfortunately, the inhibitory activity of the extract was bioassayed using lettuce seed; its activity with regard to bitterbrush embryos was not demonstrated.

If the two-step system described above is correct, it could explain why excised embryos germinate readily, but embryos in intact seeds behave as if dormant. Excised embryos have access to abundant oxygen that would rapidly deactivate an embryo-level inhibitor.

Another method for germinating dormant bitterbrush seeds without chilling is prolonged leaching in aerated water. Seeds exposed to this treatment germinate in the water in 1 to 2 weeks (K. Jorgensen personal communication). This treatment may work by leaching an inhibitor, but its location within the seed is not known.

Hydrogen peroxide has also been used to break bitterbrush seed dormancy (Everett and Meeuwig 1978; Young and Evans 1981). It is also effective in breaking dormancy of many conifer seeds (Ching and Parker 1958; Riffle and Springfield 1968; Shearer and Tackle 1960). The efficacy of hydrogen peroxide may be due to its participation in coat oxygen-trapping reactions. In rice, the level of the enzyme peroxidase in the dormancy-imposing structure (the hull) has been correlated with the degree of seed dormancy (Navasero and others 1975). Peroxidase apparently functions in conjunction with endogenously produced peroxide in the oxidation of oxygen-sink compounds (White and others 1964). If a similar system functions in bitterbrush, hydrogen peroxide could saturate the sink compounds and slow or stop the funnelling of oxygen into the trapping system. Coat oxygen-trapping mechanisms have also been demonstrated in beets, in species of Chenopodium, and in other woody Rosaceae (Côme 1967; Coumans and others 1976; Dorne 1981; Heydecker and others 1971).

Dormancy-breaking chemicals that probably function at the embryo level include thiourea and gibberellic acid. Thiourea has been used as a seed pretreatment of field-sown bitterbrush seed (Everett and Meeuwig 1978; Neal and Sanderson 1975; Pearson 1957; Young and Evans 1981). Its mechanism of action is presently unknown, though it may function in some way to block an embryo-level inhibitor or interfere with its generation (Bewley and Black 1982). Much less work has been done on the effects of gibberellic acid in bitterbrush. The results of McConnell (1960) suggest that it can interact synergistically to shorten the required prechill period, but cannot replace prechill entirely.

In the present study, we looked at the interaction between prechill requirements and seed pretreatments, including soaking in water and hydrogen peroxide, as a function of seed source. We examined the effects of short-term dry-afterripening on the prechill requirement for various accessions. The effects of interruption of the prechill period with warm interruptions of various durations were also investigated.

MATERIALS AND METHODS

Seed collection was carried out during the summer of 1986 by the authors and by cooperators in various parts of the West (table 1). The fruits were hand rubbed on a rubbing board to remove the pericarps and cleaned in a table model fanning mill that removed most of the shrivelled seed. The cleaned seed was stored in manila packets under laboratory conditions until use. Only intact, nonshrivelled seeds with no visible insect damage were used.

Experiments were initiated in September 1986. Initial viability for each lot was estimated on

Table 1--Collection locations for antelope bitterbrush seed collections used in experiments. Sources followed by an asterisk were included in the 13-accession March 1987 experiment

Seed source		Lat.	Long.	Alt.
Crater's Moon	ID*	43°30' N.	113°33' W.	5500'
Hagerman	ID	42°46' N.	114°53' W.	2950'
Idaho City	ID	43°50' N.	115°50' W.	4000'
Lucky Peak	ID	43°37' N.	115°59' W.	2900'
Middleton	ID	43°49' N.	116°40' W.	2500'
More's Creek	ID	43°39' N.	115°48' W.	3200'
Reynolds Creek	ID*	43°07' N.	116°46' W.	4900'
St. Anthony	ID*	44°03' N.	111°57' W.	5800'
Wells	NV*	41°07' N.	114°48' W.	6000'
Celilo	OR*	45°38' N.	120°58' W.	400'
Eagle Creek	OR	44°52' N.	117°14' W.	2900'
Halfway	OR	44°50' N.	117°06' W.	3050'
Keating	OR	44°51' N.	117°28' W.	2800'
Mitchell	OR	44°34' N.	120°10' W.	3000'
Cottonwood Creek	UT	40°30' N.	110°12' W.	7700'
Diamond Mountain	UT*	40°37' N.	109°22' W	7200'
Fountain Green	UT*	39°37' N.	111°37' W.	6000'
Grouse Creek	UT	40°32' N.	109°53' W.	7500'
Mosby Canyon	UT	40°34' N.	109°48' W.	7600'
Mt. Pleasant	UT*	39°32' N.	111°24' W.	6400'
Mountain Dell	UT*	40°47' N.	111°42' W.	5800'
Nephi Ridge	UT	39°21' N.	111°55' W.	5400'
Panguitch Creek	UT	37°46' N.	112°30' W.	7800'
Panguitch Lake	UT*	37°42' N.	112°37' W.	8400'
Red Canyon	UT*	37°43' N.	112°16' W.	7900'
Scofield	UT*	39°52' N.	111°07' W.	7800'
West Fairview	UT	39°37' N.	111°29' W.	6000'
Wenatchee	WA*	47°25' N.	120°17' W.	650'

four replications of 25 seeds using tetrazolium staining techniques (Grabe 1972). The seeds were first imbibed for 12 hours on germination blotters at room temperature (about 22 °C). The embryos were then excised by cutting the seed coat and the endosperm at the cotyledon end and applying firm pressure to the radicle end with thumb and forefinger. The embryos were placed in 1 percent tetrazolium chloride solution for 12 hours. Embryos stained completely red or with only minor unstained patches on the cotyledons were classed as viable. The viability estimates thus obtained are highly correlated with germination percentages for adequately prechilled bitterbrush seeds (Meyer and others 1986).

Completely randomized designs were used for all experiments. For each seed collection, four replications of 25 seeds were used per treatment. The seeds were placed between standard blue germination blotters in 100 mm plastic petri dishes and incubated in the dark. Germination tests were carried out at 15 °C for a period of 4 weeks. Blotters were moistened with tapwater as needed. Prechill treatments were carried out in the dark at 2 °C; seeds were prechilled and germinated in the same petri dishes. Seeds were considered germinated when the radicles extended at least 5 mm or showed a definite geotropic response. Germinated seeds were counted and removed at least weekly.

The first experiment tested the effect of postharvest storage period (seed age) on germination response to a 2-week prechill. All 28 seed accessions were subjected to this treatment in September 1986, after a mean postharvest period of 2 months, and again in May 1987, after a mean postharvest period of 10 months.

In February 1987, seeds from three sources (Celilo, OR, Reynolds Creek, ID, and Red Canyon, UT) were subjected to a factorial combination of hydrogen peroxide soaking concentrations and soaking times. Concentrations included 0 (water control), 1, 3, and 10 percent; time periods were 1, 6, and 24 hours. Dry seeds were placed in beakers containing the peroxide solutions and left to stand for the indicated period of time. They were then rinsed several times with tap water and transferred directly to petri dishes while still fully imbibed.

In March 1987, seeds from 13 sources (see table 1) were subjected to an experiment that included 13 treatments. Prechill periods of 0, 2, 4, and 6 weeks were combined factorially with two presoak treatments, with and without a 24-hour standing water presoak. In addition, a 6-hour 1 percent peroxide presoak was combined with 0-week and 2-week prechill. The final three treatments involved interrupting a 4-week prechill period with a period at 15 °C after the first 2 weeks; periods of interruption were 1, 4, and 7 days.

To determine whether the peroxide treatment affected seed viability, seeds remaining at the end of the germination period in the 2-week prechill peroxide treatment were subjected to tetrazolium staining as described above. This procedure was also employed at the end of 6-week prechill treatments, as a check for dormant seeds.

Analysis of variance techniques were used to analyze experimental results. Data were arcsine transformed prior to analysis, but untransformed means are used in the data presentation. In the seed age experiment, the tetrazolium viability estimates were used to convert the results to a percentage of viable seed basis for each collection prior to analysis. In the 13-accession experiment, the tetrazolium viability data were included in the analysis as a control treatment. The Student-Newman-Keuls means separation test was used to evaluate the significance of differences between means in each experiment.

Linear regression techniques were used to analyze the relationships between treatments on a by-source basis. Data used for regression analysis were converted to a percentage of viable seed basis to minimize the effects of source differences in total viability.

RESULTS

Prechill Requirement

In general, the prechill requirement of 8-month-old bitterbrush seed was completely satisfied by 6 weeks at 2 °C (fig. 1). Only one source (Celilo, OR) had more than 2 percent dormant seed remaining at the end of this treatment.

Germination response to the 4-week prechill was significantly lower than the response to the 6-week prechill, averaging 88 percent of viable seed. Four-week prechill response also showed more between-population variation. The absolute percent increase in germination with an increase from 4 to 6 weeks of prechill varied from nil for the Red Canyon, UT, seed to 23 percent for the Celilo, OR, seed.

Germination response to a 2-week prechill averaged 43 percent of viable seed and showed the widest between-population variation of any prechill treatment, ranging from 18 percent of viable seed (Celilo, OR) to 78 percent of viable seed (Red Canyon, UT). Response to the no-prechill control treatment was uniformly low, averaging approximately 2 percent and no higher than 5 percent of viable seed from any source.

Presoak by Prechill Interaction

A 24-hour water presoak significantly increased the germination of nonchilled seeds, but mean germination percentage for this treatment was still only 11 percent of viable seed, with a maximum of 24 percent for seed from the Red Canyon, UT, source (fig 1).

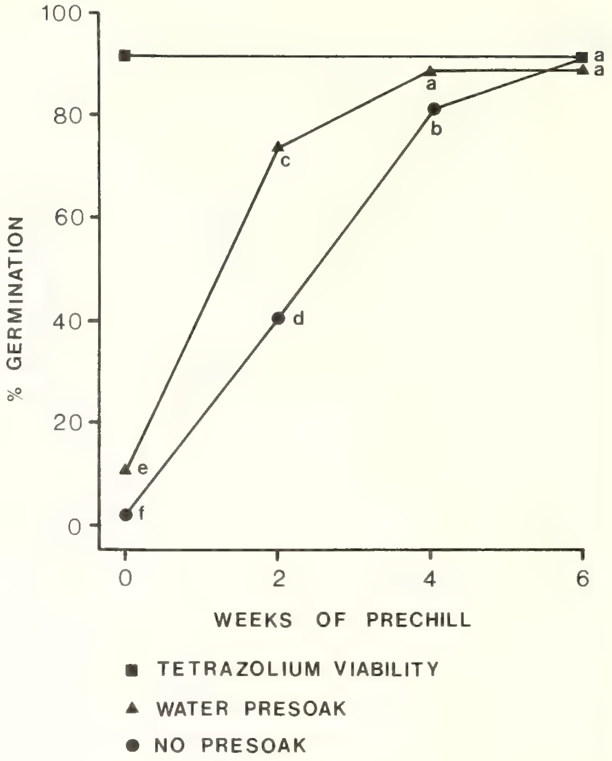

Figure 1--Mean germination response of 8-month-old antelope bitterbrush seed from 13 sources to a factorial combination of soaking and prechill treatments. The horizontal line across the top of the graph represents mean total viability, as determined by a tetrazolium test on a separate sublot of each seed collection. Points followed by the same letter have values not significantly different at the $p < 0.05$ level.

Water presoak interacted synergistically with the 2-week prechill, nearly doubling mean percentage germination over the no-soak 2-week prechill treatment (fig. 1). This treatment gave a response statistically equivalent to total viability for seed from the least dormant Red Canyon, UT, source and approached the no-presoak 4-week prechill response for seed from most sources.

Presoak had a significant effect on response to a 4-week prechill (fig. 1). Presoaked seeds germinated to full viability after a 4-week prechill, while unsoaked seeds showed a significant increase in response when prechill was increased from 4 to 6 weeks.

Results of the factorial combination of water presoak and prechill treatments show that a water presoak as applied in this experiment can reduce the prechill requirement significantly but cannot effectively substitute for prechill. It has no effect on the germination of adequately prechilled seed.

Table 2--Germination response of antelope bitterbrush seeds from three sources to a factorial treatment of hydrogen peroxide soaking concentrations and soaking times

Source	Concentration (%)	Germination percentage		
		Soaking time (hours)		
		2	6	24
Three-source mean	0	5.7	7.3	13.7
	1	34.7	[1]57.3*	41.7
	3	56.0*	61.7*	9.3
	10	62.0	11.7	1.6
Red Canyon, UT	0	10	18	26
	1	43	72*	42
	3	69*	78*	22
	10	75*	31	5
Reynolds Creek, ID	0	4	3	6
	1	29	48	50
	3	54*	69*	6
	10	74*	4	0
Celilo, OR	0	3	1	9
	1	32*	52*	33*
	3	45*	38*	0
	10	37*	0	0

[1] Within each source, means followed by an asterisk are not significantly different from the maximum at the $p < 0.05$ level.

Effects of Hydrogen Peroxide.

Hydrogen Peroxide did not break dormancy completely in any of the seeds from the three sources tested in the soaking concentration-soaking time factorial (table 2). All accessions showed a similar pattern of response, with short to medium durations and medium to high concentrations producing the highest germination percentages. Lengthening the soak period produced a corresponding increase in germination over 24 hours only for the water control. The drop in germination once the optimum period had been reached was increasingly precipitous at higher concentrations. These results suggest that the dormancy-breaking action of the peroxide is accompanied by processes that render the embryo itself less able to germinate, not really a surprising result considering the caustic nature of the compound. These negative actions were sometimes evident as radicle-tip necrosis in the germinated seeds, a symptom not noted in the water controls. The magnitude of the response to peroxide varied; the Red Canyon, UT, seeds were much more responsive than the Celilo, OR, seeds.

Peroxide was also much more effective than a water presoak in breaking the dormancy of unchilled seeds in the 13-accession experiment (table 3). When the seeds were prechilled for 2 weeks after the soak treatments, however, the water presoak and peroxide presoak treatments were comparable.

Table 3--Mean germination response of seeds from 13 antelope bitterbrush sources to a factorial combination of presoak and prechill treatments, compared with initial viability

Treatment	Mean germination percentage
Initial viability	[1]91.5a
No prechill	
No presoak	1.8f
Water presoak	10.0e
Peroxide presoak	41.3d
Two-week prechill	
No presoak	39.5d
Water presoak	74.1b
Peroxide presoak	
Germinated seeds	70.1c
Germinated + dormant seeds	88.5a

[1] Means followed by the same letter are not significantly different at the $p < 0.05$ level.

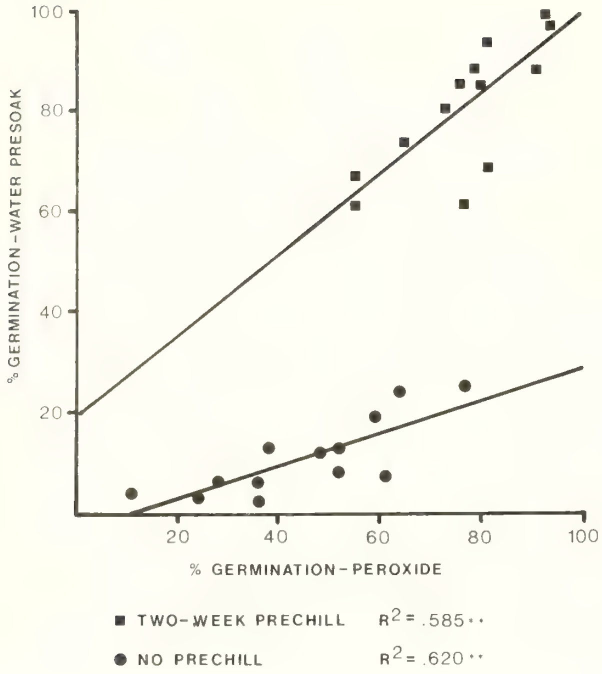

Figure 2--The relationship between germination response to a 24-hour water soak and germination response to a 6-hour 1 percent peroxide soak with no prechill (lower regression line), and after 2 weeks of prechill (upper regression line) for antelope bitterbrush seed from 13 sources.

This was not due to any negative effect of the peroxide on the viability of the remaining seeds, since the sum of germinated and dormant seeds in this treatment was equivalent to initial viability.

When the water and peroxide presoak treatments are compared on a source-by-source basis, it is evident that accessions that respond well to peroxide also tend to respond well to water presoak, resulting in a significant linear relationship between the two treatment variables both in the no-prechill control and after 2 weeks of prechill (fig. 2).

Effects of Seed Age on the Prechill Requirement

Postharvest storage period had a significant effect on the germination response to a 2-week prechill (table 4). In the 28-accession experiment an increase in seed age from 2 months to 10 months resulted in a mean germination increase from 12.5 to 35.5 percent of viable seed. When data from the 2-week prechill treatment in the March experiment are compared with data from the September and May experiments for the same 13 accessions, a significant increase in germination response with a increase from 8 to 10 months in storage is evident. These results show that short-term afterripening at room temperature can affect the degree of dormancy of antelope bitterbrush seeds.

Table 4--Germination response to a 2-week prechill as a function of seed age (storage period). Results are averaged across collections for each group and based on relative germination percentages (percent of viable seed) for each accession

Experiment	Relative germination percentage
28 Collections--1986 seed	
Mean seed age--2 months	[1]12.5b
Mean seed age--10 months	35.5a
13 Collections--1986 seed	
Mean seed age--2 months	13.5c
Mean seed age--8 months	30.7b
Mean seed age--10 months	37.9a

[1] Within each group, means followed by the same letter are not significantly different at the $p < 0.05$ level.

When germination percentages after 2 months and after 10 months of storage are compared on a source-by-source basis, it is evident that accessions that were least dormant at 2 months tended to be least dormant at 10 months, resulting in a significant linear relationship between the two variables (fig. 3). The rate of dry-afterripening of more dormant seedlots was highly variable, however. The Middleton, ID, seedlot did not respond at all to a 2-week prechill at 2 months and showed no increase at 10 months. In contrast, the Panguitch Lake, UT, seedlot showed an increase in germination response from 5 to 47 percent of viable seed over the same storage period.

Effects of Interrupted Prechill

Seed subjected to a 4-week prechill interrupted after 2 weeks by a period of 7 days at 15 °C showed an absolute decrease of about 30 percent in total germination compared with the 4-week uninterrupted prechill control (table 5). A similar effect was achieved with a 4-day mid-prechill interruption, while germination after a 1-day interruption was not significantly different from the uninterrupted control. In the 4-day and 7-day interruption treatments, the additional 2 weeks of prechilling produced an average of only a 10 percent absolute increase in germination over the 2-week prechill, while in the no-interruption 4-week control, the increase over a 2-week prechill was over 40 percent. These results suggest that the seeds left ungerminated after the 4-day and 7-day interruptions had undergone a process while imbibed at 15 °C that increased their level of dormancy.

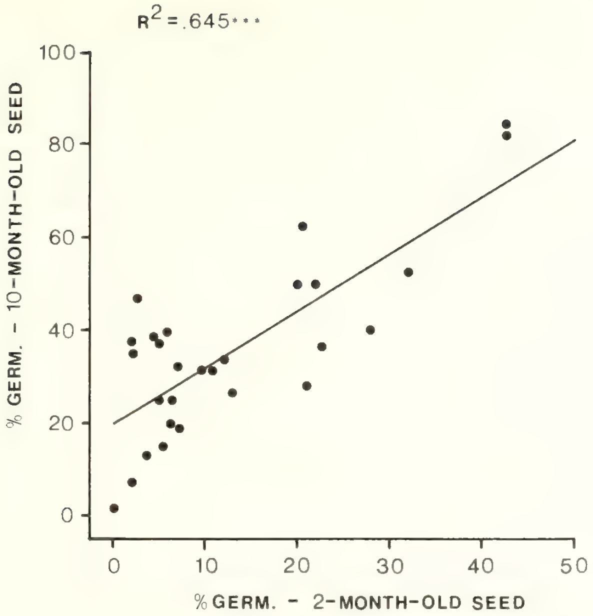

Figure 3--The relationship between the germination response of 2-month-old seed and that of 10-month-old seed to a 2-week prechill treatment. Results are expressed on a percentage of viable seed basis for each of the 28 seed collections.

Table 5--Mean germination response of seeds from 13 antelope bitterbrush sources to a series of prechill and interrupted prechill treatments. Interruptions followed the first 2 weeks of 4-week prechill periods

Treatment	percentage
4-week prechill	
No interruption	[1]81.4a
1-day interruption	82.7a
4-day interruption	52.8b
7-day interruption	51.5b
2-week prechill	39.5c

[1] Means followed by the same letter are not significantly different at the $p < 0.05$ level.

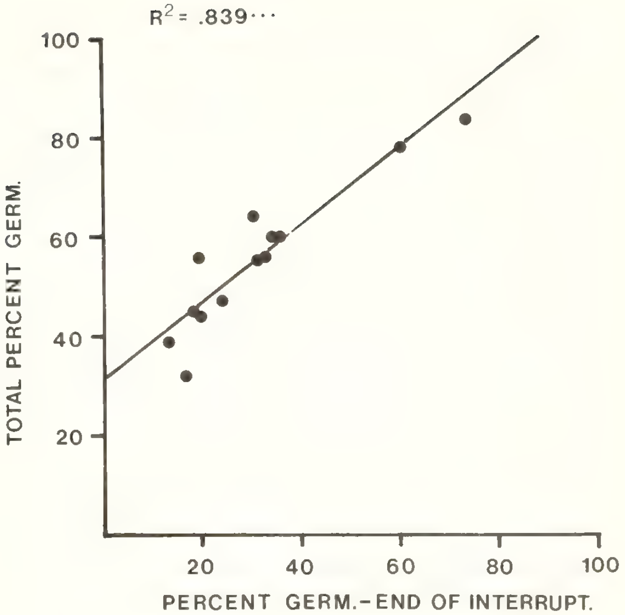

Figure 4--The relationship between germination percentage at the end of the 7-day interruption and total germination at the end of the final germination period for the 4-week 7-day interrupted prechill treatment. Values for each of the 13 seed collections are expressed as a percentage of viable seed.

Many of the seeds that germinated in the 4-week 7-day interrupted prechill in fact germinated during the interruption, and the total number of seeds germinating at the end of the test was closely correlated with the number that germinated during the interruption period (fig. 4). If we consider only viable seeds remaining at the end of the second 2 weeks of prechill, we see that from 17 to 49 percent of these seeds germinated, with an average of 37 2.5 percent (mean + standard error). No clear trends are evident on a source-by-source basis. The warm interruption effectively induced secondary dormancy (increased dormancy) in still-dormant seeds of all sources.

DISCUSSION

The required prechill period reported here (4-6 weeks) agrees well with earlier values reported for antelope bitterbrush (Young and Evans 1981). Considering the range of site types over which collections in this study were made, there was relatively little between-source variation in the prechill requirement, and this variation was not correlated in any obvious way with site conditions.

These results are in contrast to those reported for some other woody Rosaceae. In wild pear species, length of required prechill was positively correlated with the length and severity of the winter at the site of seed collection (Westwood and Bjornstad 1968). In almond varieties, the length of the prechill required to break seed dormancy was positively correlated with the prechill required to break bud dormancy (Kester 1969). This in turn was related to the provenance of the variety. In both pear and almond, control seems to be at least partly genetic and to reside at the embryo level, since crosses of long-seed-prechill plants with short-seed-prechill plants generally produce seeds with intermediate prechill requirements in a common garden. In rose cultivars, the length of the prechill requirement was strongly affected by year-to-year variation in common garden conditions during the latter stages of seed maturation (Von Abrams and Hand 1956). Seed ripened at warmer temperatures was less dormant than seed ripened at cooler temperatures. There are apparently genetic differences in the prechill requirements of different rose species as well (Densmore and Zasada 1977; Semeniuk and Stewart 1962; Svejda and Poapst 1972). In bitterbrush, no clear trends in the effect of genotype or of predispersal environment on prechill requirement have emerged.

Shortening or eliminating the prechill requirement with a water presoak has been effective for many species (Barton 1954; Janerette 1979). The usual explanation is the leaching of an embryo-level or seed-coat level inhibitor, though this has only sometimes been rigorously demonstrated (Bewley and Black 1982). The presoak treatment used here was not sufficient to substitute for prechill, but it may have lowered the level of some inhibitor, possibly at the embryo level, to a point that approached a threshold level. It thus interacted synergistically with a 2-week prechill to produce germination percentages that greatly exceeded the sum for the two treatments separately.

The hydrogen peroxide treatment, unlike the water presoak, was able to substitute for prechill to a substantial degree. It may work by oxidizing coat level phenolics that are not readily leached with water. Its interaction with a 2-week prechill was essentially additive, which suggests that it works by a different mechanism than the water presoak. The fact that accession response to peroxide was highly correlated with response to water presoak may indicate that accession differences are due to differences in embryo inhibitor levels. Seeds with lower levels would be brought closer to a threshold level by soaking. They would also require less oxygen for deactivation and would thus respond more positively at a given level of immobilization of a coat oxygen trap.

The reduction of seed dormancy as a consequence of dry storage has been observed in a wide range of species, but the mechanisms remain largely unknown (Bewley and Black 1982). The effect may be to increase the range of conditions over which germination may take place, to make possible the germination of previously dormant seeds, or, as in the case of bitterbrush, to shorten the period of pretreatment necessary to permit germination of previously dormant seeds. The rate of dry-afterripening is temperature dependent and may be much accelerated at higher temperatures for some species (Bewley and Black 1982; Capon and Van Asdell 1967; Taylorson and Brown 1977). The storage temperature used in this study (20 °C) was probably not high enough for maximum rates of afterripening and certainly did not approach summer temperatures likely to be experienced by bitterbrush seeds in the field (Ferguson 1972), or even in uncontrolled warehouse storage. The effect of high temperature on the rate and degree of dry-afterripening in antelope bitterbrush has not yet been systematically investigated.

The induction of secondary dormancy in seeds maintained imbibed under conditions not suitable for germination is also a well-known phenomenon (Bewley and Black 1982). In rosaceous shrub seeds, the degree of dormancy is often increased at temperatures above a certain threshold value and decreased at temperatures below it. At the threshold or compensating temperature, no change in dormancy takes place (Bulard 1985; Kester 1969; Stewart and Semeniuk 1965). The threshold value varies from species to species and even among accessions of the same species. The dormancy-breaking process is thus reversible, and interruptions in the prechill period produce essentially the same result as that reported here for bitterbrush, an increase in the prechill requirement of the remaining ungerminated seeds. The observations made here are consistent with the idea of an embryo-level inhibitor whose production or efficacy is enhanced at low oxygen levels, since the oxygen level in the interior of the intact seed is much decreased at higher temperatures. A further implication is that the prechill requirement of a seedlot could be increased by imbibing the seeds at warm temperatures prior to the initiation of any prechill. Preliminary data (Meyer and Monsen in preparation) support this possibility for bitterbrush.

The evidence presented here is congruent with a seedcoat oxygen trap-oxidizable inhibitor model for bitterbrush seed dormancy, but it by no means presents rigorous proof for such a model. Much more detailed work at the physiological level will be necessary before the processes involved can be fully understood.

The intuitive idea that bitterbrush seed collections from sites with long, severe winters will have a longer prechill requirement than collections from sites with short, mild winters was not supported by the 13-accession study. All 13 accessions had requirements of 6 weeks or less, and only one (Red Canyon) was rendered largely germinable by a treatment of less than 4 weeks.

In the 28-accession, fresh seed, 2-week prechill experiment, the least dormant sources were mostly high-elevation sources from central and southern

Utah, while most of the strongly dormant sources were from low elevations on the Snake River Plains and the Columbia Plateau of Idaho and Oregon. This trend was not without exceptions, but it was strong enough to prompt an attempt at interpretation. Results of the afterripening and interrupted prechill experiments may provide clues to a possible explanation.

Seeds of low-elevation northern sources ripen early in the summer and are exposed to a long period of warm, dry conditions prior to the onset of prechill. If dry-afterripening is accelerated at high temperatures, these seeds could become susceptible to germination during the hazardous fall period after rains have begun but before the severe frosts of winter. They may need to be strongly dormant initially to avoid afterripening too much during the dry summer.

Seeds of high-elevation southern sources, on the other hand, ripen late in the summer. But summers are moist, and these seeds would be exposed to warm, moist conditions after dispersal. Such conditions may be effective in increasing their prechill requirement to such a degree that it might not be satisfied by the on-site winter prechill duration. Such seeds would increase their chances of survival if dispersed in a relatively nondormant state, providing that they are completely dormant under the conditions of the summer-moist pretreatment itself.

Even if all seed from all sources started out with a similar degree of dormancy, experiences after dispersal would tend to condition them for the prechill period likely to be encountered at their respective sites. Seeds from sites with hot, dry summers and short, mild winters would tend to become less dormant after dispersal through dry-afterripening. Seeds from sites with warm, moist summers and long, cold winters would tend to become more dormant after dispersal because of dormancy-deepening processes that may operate on imbibed seeds at warm temperatures.

The data presented here are not sufficient to demonstrate an ecological relationship between seed characteristics and site characteristics that affect seeds after dispersal. These ideas represent working hypotheses that are currently under continuing investigation using both laboratory and field burial techniques.

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REFERENCES

Barton, L. V. 1954. Effects of presoaking on dormancy in seeds. Contributions to the Boyce Thompson Institute. 17: 435-438.

Basile, J. V. 1967. An annotated bibliography of bitterbrush (Purshia tridentata [Pursh] DC). Res. Paper INT-44. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 27 p.

Basile, J. V.; Holmgren, R. C. 1957. Seeding depth trials with bitterbrush (Purshia tridentata) in Idaho. Res. Paper INT-54. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Bewley, D. D.; Black, M. 1982. Physiology and biochemistry of seeds in relation to germination. II. Viability, dormancy, and environmental control. Berlin: Springer-Verlag. 375 p.

Bulard, C. 1985. Intervention by gibberellin and cytokinin and the release of apple embryos from dormancy: a reappraisal. New Phytology. 101: 241-249.

Capon, B.; Van Asdall, W. 1967. Heat pretreatment as a means of increasing germination of desert annual seeds. Ecology. 48: 305-306.

Ching, T. M.; Parker, M. C. 1958. Hydrogen peroxide for rapid viability tests of some coniferous tree seeds. Forest Science. 4: 128-134.

Côme, D. 1967. L'inhibition de germination des graines de pommier (Pirus malus) nondormantes. Role possible de phenols tegumentaires. Annales des Sciences Naturelles Botanique et Biologie Vegetal VIII: 371-378.

Côme, D.; Tissaoui, T. 1973. Interrelated effects of inhibition, temperature, and oxygen on seed germination. In: Heydecker, ed. Seed ecology. University Park, PA: Pennsylvania State University Press: 157-168.

Coumans, M.; Come, D.; Gaspar, T. 1976. Stabilized dormancy in sugarbeet fruits. I. Seed coats as a physicochemical barrier to oxygen. Botanical Gazette. 137: 274-278.

Densmore, R.; Zasada, C. 1977. Germination requirements of Alaskan Rosa acicularia. Canadian Field Naturalist. 91: 58-62.

Dorne, A. J. 1981. Variation in seed germination inhibition of Chenopodium bonus-henricus in relation to altitude of plant growth. Canadian Journal of Botany. 59: 1893-1901.

Dreyer, D. L.; Trousdale, E. K. 1978. Cucurbitacins in Purshia tridentata. Phytochemistry. 17: 325-326.

Edwards, M. M. 1968. Dormancy in seeds of charlock. II. The influence of the seed coat. Journal Experimental Botany. 19: 583-600.

Edwards, M. M. 1969. Dormancy in seeds of charlock. IV. Interrelationships of growth, oxygen supply, and concentration of inhibitor. Journal Experimental Botany. 20: 876-894.

Edwards, M. M. 1973. Seed dormancy and seed environment--internal oxygen relations. In: Heydecker, W. ed. Seed ecology. University Park, PA: Pennsylvania State University Press: 169-188.

Evans, R. L.; Young, J. A. 1977. Bitterbrush germination with constant and alternating temperatures. Journal of Range Management. 30: 30-32.

Evans, R. L.; Young, J. A.; G. L. Cluff; McAdoo, J. K. 1983. Dynamics of antelope bitterbrush seed caches. In: Tiedemann, A. R.; Johnson, K. L. eds. Proceedings--Research and management of bitterbrush and cliffrose in western North America. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 195-202.

Everett, R. L.; Meeuwig, R. O. 1978. Hydrogen peroxide and thiourea treatment of bitterbrush seed. Res. Note INT-196. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 6 p.

Ferguson, R. B. 1962. Growth of single bitterbrush plants versus multiple groups established by direct seeding. Res. Note INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 2 p.

Ferguson, R. B. 1972. Bitterbrush seedling establishment as influenced by soil moisture and soil surface temperature. Journal of Range Management. 25: 47-49.

Giunta, B. C.; Stevens, R.; Jorgensen, K. R.; Plummer, A. P. 1978. Antelope bitterbrush--an important wildland shrub. Pub. 78-12. Salt Lake City, UT: Utah State Division of Wildlife Resources. 48 p.

Grabe, D. F., ed. 1972. Tetrazolium testing handbook for agricultural seeds. Contr. 29 to the handbook on seed testing. Association of Official Seed Analysts. 62 p.

Heydecker, W.; Chetram, R. S.; Heydecker, J. 1971. Water relations of beetroot seed germination. II. Effects of the ovary cap and of the endogenous inhibitors. Annals of Botany. 35: 31-42.

Holmgren, R. C. 1956. Competition between annuals and young bitterbrush (Purshia tridentata) in Idaho. Ecology. 37: 370-377.

Hormay, A. L. 1943. Bitterbrush in California. Res. Note 9. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. 13 p.

Janerette, C. A. 1979. Cold-soaking reduces the stratification requirements of sugar maple seeds. Tree Planters Notes. 30: 3.

Kester, D. E. 1969. Pollen effects on chilling requirements of almond and almond hybrid seeds. Journal American Society Horticultural Science. 94: 318-321.

McArthur, E. D.; Meyer, S. E.; Weber, D. J. 1987. Germination rate at low temperature: rubber rabbitbrush population differences. Journal of Range Management. 40: 530-533.

McConnell, B. R. 1960. Effects of gibberellic acid and cold treatments on the germination of antelope bitterbrush seed. Res. Note PNW-187. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 4 p.

McHenry, W. B.; Jensen, L. A. 1967. Response of bitterbrush (Purshia tridentata) seed to certain germination methods. Proc. Association of Official Seed Analysis. 57: 89-95.

Meyer, S. E.; Allen, P. S.; Wilson, G. R.; Davis, T. D.; Stevens, R.; Jorgensen, K. 1986. Proposed rule for antelope bitterbrush--Purshia tridentata. Association of Official Seed Analysts Newsletter. 69(1): 21-22.

Meyer, S. E.; McArthur, E. D.; Monsen, S. B. 1987a. Infraspecific variation in the germination patterns of rangeland shrubs and its relationship to seeding success. In: Frasier, G. W.; Evans, R. A. eds. Proceedings of symposium, Seed and seedbed ecology of rangeland plants, 21-23 April, 1987, Tucson, AZ. Springfield, VA: U.S. Department of Agriculture, Agriculture Research Service: 82-92.

Meyer, S. E.; Monsen, S. B, (In preparation). Effect of high-temperature pretreatments on germination of antelope bitterbrush.

Meyer, S. E.; Monsen, S. B. (In preparation). Seed germination ecology of big sagebrush (Artemisia tridentata).

Meyer, S. E.; Monsen, S. B.; Jorgensen, K. 1987b. Seed source effects in the germination of antelope bitterbrush. Abstract 267. Abstracts of the fortieth annual meeting of the Society for Range Management, February 8-13, 1987, Boise, ID. Denver, CO: Society for Range Management.

Navasero, E. P.; Baun, L. C.; Juliano, B. O. 1975. Grain dormancy, peroxidase activity, and oxygen uptake in Oryza sativa. Phytochemistry. 14: 1899-1902.

Neal, D. L.; Sanderson, H. R. 1975. Thiourea solution temperature and bitterbrush germination and seedling growth. Journal of Range Management. 28: 421-423.

Nord, E. C. 1956. Quick-testing bitterbrush seed viability. Journal of Range Management. 9: 193-194.

Nord, E. C. 1965. Autecology of bitterbrush in California. Ecological Monographs. 35: 307-334.

Pearson, R. O. 1957. Bitterbrush seed dormancy broken with thiourea. Journal of Range Management. 10: 41-42.

Riffle, J. W.; Springfield, H. W. 1968. Hydrogen peroxide increases germination and decreases microflora on seed of several Southwestern woody species. Forest Science. 14: 96-101.

Sanderson, H. R. 1962. Survival of rodent-cached bitterbrush seed. Res. Note PSW-211. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 4 p.

Schopmeyer, C. S., ed. 1974. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture. 883 p.

Semeniuk, P.; Stewart, R. N. 1962. Temperature reversal of afterripening in rose seeds. Proceedings American Society Horticultural Science. 80: 615-621.

Shaw, N. L.; Monsen, S. B. 1983. Phenology and growth habits of nine antelope bitterbrush, desert bitterbrush, stansbury cliffrose, and apache-plume accessions. In: Tiedemann, A. R.; Johnson, K. L. comp. Proceedings--Research and management of bitterbrush and cliffrose in western North America. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 55-69.

Shearer, R. C.; Tackle, D. 1960. Effect of hydrogen peroxide on germination in three western conifers. Res. Note INT-80. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Sherman, R. J.; Chilcote, W. W. 1972. Spatial and chronological patterns of Purshia tridentata as influenced by Pinus ponderosa. Ecology. 53: 294-298.

Stewart, R. N.; Semeniuk, R. 1965. The effect of the interaction of temperature with after-ripening requirements and compensating temperature on germination of seeds of five species of Rosa. American Journal of Botany. 52: 755-760.

Svejda, F. J.; Poapst, P. A. 1972. Effects of different afterripening treatments on germination and endogenous growth inhibitors in Rosa rugosa. Canadian Journal Plant Science. 52: 1049-1058.

Taylorson, R. B.; Brown, M. M. 1977. Accelerated afterripening for overcoming seed dormancy in grass weeds. Weed Science. 25: 473-476.

Tiedemann, A. R.; Johnson, K. L. 1983. Proceedings--Research and management of bitterbrush and cliffrose in western North America. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 279 p.

Von Abrams, G. J.; Hand, M. E. 1956. Seed dormancy in Rosa as a function of climate. American Journal of Botany. 43: 7-12.

West, N. E. 1968. Rodent-influenced establishment of ponderosa pine and bitterbrush seedlings in central Oregon. Ecology. 49: 1009-1011.

Westwood, M. N.; Bjornstad, H. O. 1968. Chilling requirements of dormant seeds of fourteen pear species as related to their climate adaptation. American Society of Horticultural Science. 92: 141-149.

White, A.; Handler, P.; Smith, E. L. 1964. Principles of biochemistry. 3d ed. New York: McGraw-Hill. 1,106 p.

Young, J. A.; Evans, R. A. 1976. Stratification of bitterbrush seeds. Journal of Range Management. 29: 421-425.

Young, J. A.; Evans, R. A. 1981. Germination of seeds of antelope bitterbrush, desert bitterbrush, and cliffrose. ARR-W-17/January 1982. Washington, DC: U.S. Department of Agriculture, Science and Education Administration. 39 p.

FIRE EFFECTS ON *AMELANCHIER ALNIFOLIA* SHRUBS DURING PHENOLOGICAL DEVELOPMENT STAGES

Nonan V. Noste, Elizabeth D. Reinhardt, and Ralph A. Wilson, Jr.

ABSTRACT: Artificial fuel beds were used to burn serviceberry shrubs with fires of known duration and intensity. Plants burned early and late during the growing season resprouted slightly better than those burned in midseason. Sprouting response was related to size of the plant, but not to ratio of dead/live stems. Plant response did not vary significantly between fire treatments. The relationships between fire treatment, fire behavior, and the heat pulse to the plant and site are discussed.

INTRODUCTION

Fire is a natural process in forest communities of western Montana and throughout the West. Wildfire has historically played a role in the succession of plant communities that contain intolerant shrubs as a seral component. Strategies to manage sites that contain intolerant shrubs include the use of prescribed fire.

Prescribed fire provides managers with a cost effective method of manipulating plant communities to increase resource production. Old decadent shrubs may produce little annual growth, and the younger more succulent plant parts may be out of reach of even large ungulates. Burning these shrubs to kill above-ground stems should result in an increase of young available sprouts from underground buds, increasing both wildlife browse production and availability.

To use prescribed fire effectively, we need to understand the relationships between fire treatment and fire effects. The effects of season, fire characteristics, and preburn plant characteristics on plant response need to be quantified to determine what time of year and type of fire best achieve above-ground stem mortality without removing the plants from the site. Opportunities for prescribed burning may be limited by lack of fuel. Natural fuel loadings may be inadequate to produce a fire that spreads through the area and is intense enough to kill the above-ground stems. Fire applied at different times of the year may produce varying shrub response. Seasonal differences in shrub response may be due to changes in plant carbohydrate reserves. They may also be due to changes in soil moisture, which affects thermal conductivity and thus the transfer of heat to underground plant parts. Understanding seasonal variations in plant susceptibility to fire will aid in development of fire prescriptions that can best meet management objectives.

Burning during the season of active growth resulted in increased mortality of shrubs in the northern Sierra Nevada (Kaufman and Martin 1985). Miller (1977) found that more rhizomes of huckleberry (*Vaccinium globulare*) survived spring fires than more severe fall fires; however, there was no seasonal difference in sprouting rate of those rhizomes that survived.

The inability to characterize and control the heat pulse to the plant has sometimes been an obstacle to understanding the seasonal response of shrubs to fire, making it difficult to separate the effects of season from the effects of fire treatment. Flinn and Pringle (1983) used water baths for heat treating eight shrub species to control the temperature and duration of the treatment. They documented seasonal variation in sprouting rates following these treatments.

Shrub response to fire may also vary with fire severity. Fire severity depends on the heat pulse up to the plant, as indicated by flame length, and heat pulse downward to the soil, as a result of burnout of ground fuels (Ryan and Noste 1985). Rhizomes subjected to nonlethal heat treatments showed increased sprouting over untreated rhizomes (Flinn and Pringle 1983). Excessive heat (usually temperatures over 55 or 60 °C) resulted in rhizome mortality. Johnston and Woodard (1985) studied the effect of fire severity on hazel (*Corylus cornuta* Marsh.) and raspberry (*Rubus strigosus* Michx.) by artificially adjusting fuel loads on small plots within a single large burn. They found that above-ground plant parts were killed even by low severity fires. They found some below-ground mortality under plots with heavy fuel loads.

The objectives of this study were to examine the effects of season and severity of fire treatment on sprouting response of one species, Saskatoon serviceberry (*Amelanchier alnifolia* Nutt.). Serviceberry is often an important winter food source for whitetail deer, mule deer, elk, bighorn sheep, mountain goats, and moose (Hemmer 1975). It has been characterized as relatively high in fire survival capability due to its massive rooting system, which is rhizomatous and deeply

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Nonan V. Noste is a forester, Elizabeth D. Reinhardt is a research forester, and Ralph A. Wilson, Jr. is a research physicist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

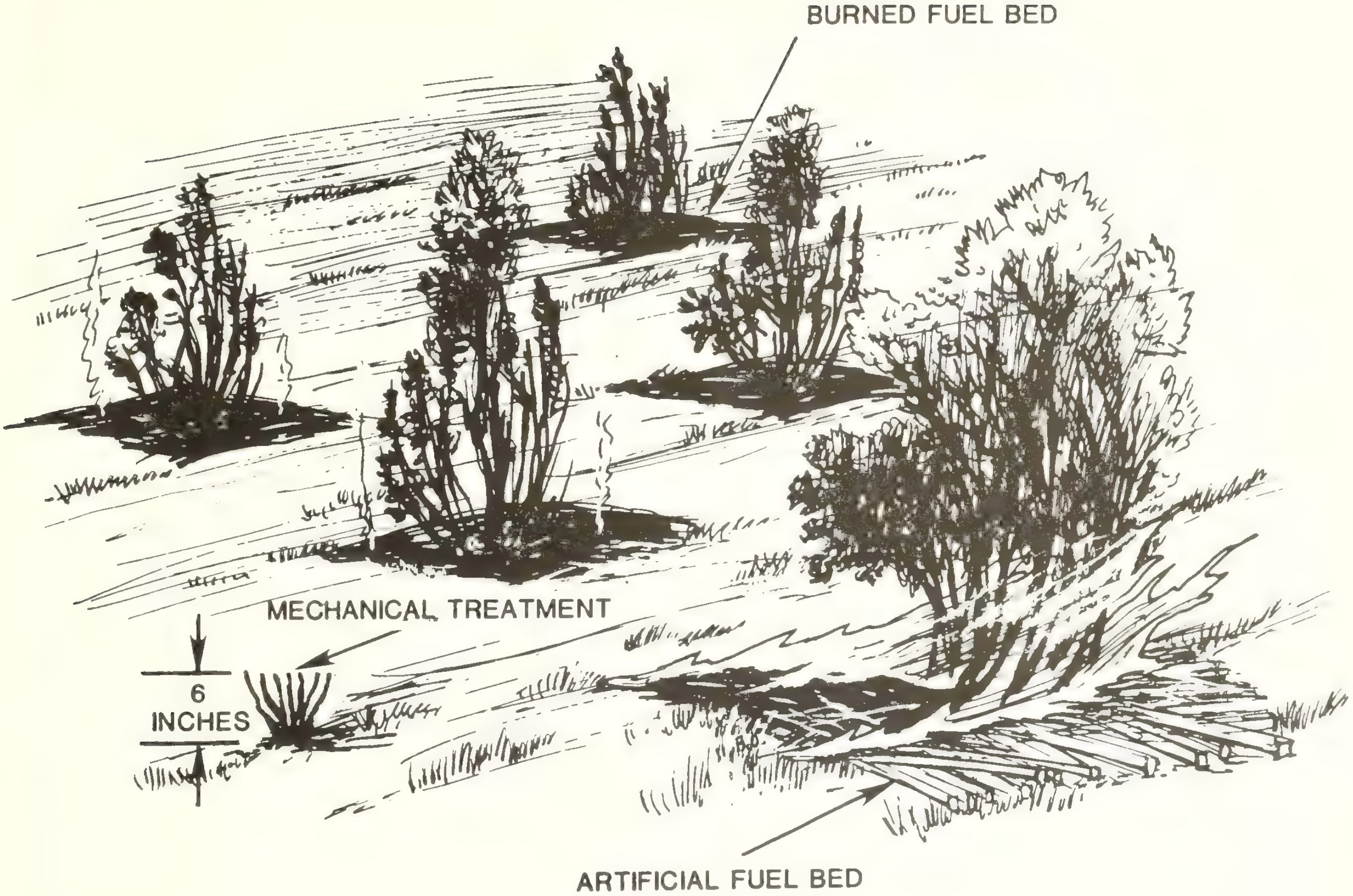


Figure 1--Plot layout showing one group of shrubs receiving the six treatments.

placed (Bradley 1984). In a study contrasting the ability of a spring and a fall prescribed burn to improve wildlife habitat, a severe fall treatment killed 15 percent of the serviceberry plants on the site, while a less severe spring treatment killed only 5 percent (Noste 1982). Sprouting response in the first 2 years following the fire was greater on the spring burn.

METHODS

Saskatoon serviceberry plants in a Douglas-fir/snowberry (*Pseudotsuga menziesii/symphoricarpus albus*) (Pfister and others 1977) habitat type north of the Ninemile Ranger Station in the Lolo National Forest in western Montana were burned in 1984 and 1985, using artificial fuel beds to produce high and low intensity, long and short duration fires by manipulating loading and fuel particle size. Heat pulses to the soil and stems were measured to characterize the treatment from these fuels.

Individual serviceberry shrubs were treated with fire during four different phenological stages. Selected plants were mature, growing in an open stand condition on relatively level ground, and not heavily browsed. Twelve groups of six plants each were used to provide three replicates of six treatments during four phenological stages of plant development:

1. Before leaf bud burst.
2. After leaves were fully developed.
3. After initial change in fruit color.
4. After first leaf coloring in fall.

The six treatments were randomly assigned to the six plants in each group (fig. 1). Five of the treatments were designed to provide a range of fire intensity and duration commonly found under natural conditions, while the sixth treatment was mechanical removal of above-ground stems:

Treatment	Fuel load		Surface/ volume	Diameter
Severity duration/	T/ac	kg/m^2	1/cm	in.
1 mod-mod	5	1	6	1/8-1/4
2 light-mod	2	0.4	6	"
3 heavy-mod	10	2	6	"
4 mod-fast	5	1	81	excelsior
5 mod-slow	5	1	3	1/2
6 clipped	-	-	-	-

Plants were measured before treatment to determine their size and condition. All stems within 0.5 m of the plant center were tallied by diameter class, height, and status (live or dead). Biomass was computed using Brown's (1976) equations. Ratio of live to dead stems was used as an indicator of plant vigor.

The plants were instrumented with thermocouples to quantify the heat treatment they received. Three stems on each shrub were instrumented with two thermocouples 10 cm above the ground, one taped to the bark surface, and another installed 2 mm underneath it, approximately at the cambium layer. This allowed documentation of the temperature gradient through the bark to the cambium. A set of four thermocouples was used to monitor heat movement into the soil. These were placed at the soil surface and 1, 3, and 5 cm below the soil surface.

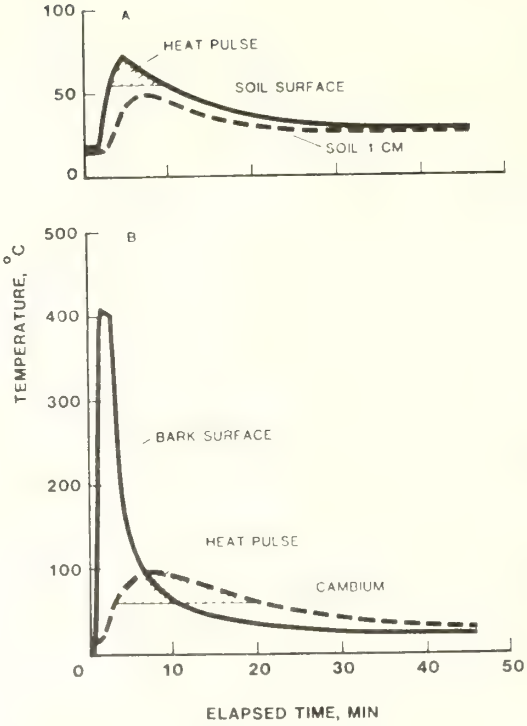
Fuels were conditioned to approximately 6 percent moisture content by storing them indoors. Litter and dead stems were removed from a 2 by 2-meter area around each shrub prior to building the artificial fuel bed. This area was then uniformly covered with the conditioned fuels (fig. 2).

Figure 2--A serviceberry shrub receiving treatment 1.

Fires were ignited along the downslope-down-wind edge of the fuel bed. Rate-of-spread was timed between metal stakes spaced at 1/2-meter intervals from a stake at the plant center. Flame length and depth were recorded at each stake. Temperature, windspeed, and relative humidity were observed at the time of the burn using a belt weather kit.

Temperatures during the burn were monitored at 30-second intervals and recorded electronically, using a Campbell Scientific CR5 digital recorder. A typical temperature profile is displayed in figure 3.

Serviceberry sprouts within 0.5 m of the plant center were counted by size class at the end of one growing season after burning as a measure of treatment response.



Figures 3A and 3B--Time temperature profiles for a representative burn. Figure 3A shows profiles for thermocouples on the soil surface and 1 cm below the soil surface, while figure 3B shows profiles for the thermocouples on the stem. The shaded areas show the "heat pulse" as it was computed for each plant.

ANALYSIS

Analysis of variance was conducted using a split plot design, with post treatment number of sprouts per shrub as the dependent variable, phenological stage as the main plot, and fire and clipping treatment as subplots. The preburn size of the shrub and ratio of dead-to-live stems were added as covariates to increase the sensitivity of the test. Post treatment sprout biomass was also used as a dependent variable. Because results were parallel, only number of sprouts will be reported.

Total heat release was computed from fuel heat content, fuel loading, rate of spread, fuel bed depth, and residence time (Rothermel 1972). The temperature profiles were used to compute a heat pulse to the cambium and the 1 cm depth in the soil. Heat pulse was defined as the area under the time temperature profile curve but above 60 °C. Fire behavior and heat pulse were summarized for descriptive purposes, and relationships between them were examined.

RESULTS

All fire treatments killed virtually all the above-ground plant parts. Little heat increase was observed below 1 cm depth in the soil. All plants resprouted vigorously.

Table 1--Split plot analysis of variance of serviceberry sprout response to treatment and phenological stage with ratio of dead/living stems and size of shrub as covariates

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of F
Main plot analysis					
Plant stage	3	11743	3914	6.86	0.0008
Error A (Replications within stage)	8	12056	1507	2.64	0.0209
Sub-plot analysis					
Treatments	5	2763	553	0.97	0.4495
Stage x treatment	15	14697	980	1.72	0.0891
Covariates					
Size of shrub	1	12604	12604	22.08	0.0001
Live/dead ratio	1	60	60	0.10	0.7481
Error B (Error A x treatment)	38	21688	571		
Hypotheses test using the "A" error term					
Plant stage	3	11743	3914	2.60	0.1247

No significant differences at the 90-percent confidence level were found between the five fire and one clipping treatments (table 1). Number of postburn sprouts was positively and significantly related to preburn size of the shrub. Plant sprouting response was not significantly correlated to ratio of live-to-dead stems. There was some indication that spring and fall burns encourage sprouting (tables 2a, 2b); however, the relationship between sprouting and phenological stage was not significant at α = 0.12, and might be described as being "marginally significant."

Fire behavior and heat pulse varied significantly between the treatments (tables 3 and 4). There was a positive correlation between total heat release, and soil and stem heat pulse. There was no correlation, however, between the observed fire behavior parameters and heat pulse to the stem or soil (table 5). The relationship of soil heat pulse to stem heat pulse was insignificant with a correlation coefficient of 0.10.

DISCUSSION

The weak relationship of sprouting response to phenological season of treatment suggests that timing of burn treatment is not an important managerial concern. Similar results can be expected from spring, summer, and fall fires, although a slightly reduced sprouting response may be expected following summer treatment. This slightly reduced sprouting rate may be due to lower carbohydrate reserves in midseason, as plants expend their stored carbohydrates in leaf development and shoot elongation. Stored carbohydrates were not measured in this study, however.

Table 2a--Serviceberry sprout response for four phenological stages of plant development (n=72)

Phenological stages	Average number of sprouts/plant
Before leaf bud burst	89
After leaves are fully developed	59
Initial change in fruit color	76
First leaf coloring in fall	90

Table 2b--Serviceberry sprout response to treatment

Treatment No.	Number of sprouts/plant
1. mod-mod	88
2. light-mod	72
3. heavy-mod	75
4. mod-fast	81
5. mod-slow	81
6. clip	73
Mean	78

All above-ground stems were killed by all five burn treatments, while rhizomes did not receive

Table 3--Fire behavior characteristics of five fire treatments

Treatment	Rate of spread m/min	Flame depth dm	Flame length dm	Residence time min	Total heat release mJ/m^2
	mean				
1	0.47	3.6	5.1	1.6	52.0
2	0.16	2.3	2.1	4.1	20.0
3	0.37	4.9	9.9	1.4	105.0
4	4.05	4.8	14.2	0.6	41.0
5	0.12	3.0	2.8	4.5	44.0
Number	68.00	68.00	68.00	68.00	69.0
F ratio	3.26	3.74	33.64	8.57	11.57
Pr >F	0.02	0.01	0.00	0.00	0.00

much heat treatment. This indicates that even low intensity fires are sufficient to top kill serviceberry plants, and that fires in natural fuels are unlikely to damage underground buds and remove plants from the site, at least for the range of conditions we tested. Evidently managers have a large window of opportunity in treating serviceberry shrubs with fire. Successful burning to top kill serviceberry shrubs seems not to be limited by a need to achieve a restricted range of fire intensities. Conditions that allow a continuous fire may be used to set the lower limit for burn prescriptions. Upper limits may be set by control constraints or constraints derived from other resource objectives. In situations where there is deep duff or large amounts of woody fuel, one might expect to see some below-ground mortality. If this is a concern, prescriptions should be set to burn when duff moistures are high.

The five fire treatment fuel loads were arbitrarily chosen to yield a range of heat pulse to the site and consequently a range of stem kill. Evidently this range was not great enough to create a range in plant response. Because sprouting did not relate to our treatments, we did not attempt to relate plant responses to fire characteristics. The fire characteristics of the five treatments may, however, be of interest in designing future studies or operational burns. Heavier loadings may cause below-ground mortality, while lighter loads of fine fuels might not kill all aboveground stems.

The fuel beds for the five fire treatments were designed by using the fire behavior model (Rothermel 1972) to identify fuel loads and sizes that would result in desired fire characteristics. These prescribed fire characteristics and those actually achieved are shown in table 6. Observed flame lengths were similar to predicted flame lengths. Actual residence times were longer than anticipated, but generally the same order of magnitude. Total heat release calculated from the observed spread rate assumes 100 percent burning efficiency, hence these values are unreasonably large, but are in excellent order with the predicted values.

Table 4--Heat pulse from five fire treatments

	Fire characteristics		
	Heat pulse		Time
	Soil	Stem	Above 60 °C
Treatment	min * deg above 60		Min.
	mean		
1	388	758	8.4
2	21	226	5.5
3	1561	667	17.2
4	88	223	10.5
5	521	577	11.2
Number	52	52	57
F ratio	2.70	4.23	1.0
Prob F	0.04	0.005	0.40

SUMMARY AND CONCLUSIONS

Response to treatment generally followed the expected pattern. Larger plants resprouted better. Resprouting was slightly less for plants burned during the growing season. Resprouting was not related to fire severity for the fuel loads tested. There was no relationship between observed fire behavior and the heat pulse to the plants.

Phenological stage had a marginal effect on sprouting response. Plants do not resprout quite as well if burned during the "leafed out" and "fruiting" stages. The reason may be low carbohydrate reserves. Study results support the practice of spring and fall burning to increase the shrub component of stands, and midseason burning to reduce shrubs, but suggest that season of burn is not an important factor in serviceberry response to fire.

The size of the shrub was positively related to sprouting response, while the proportion of dead stems in the plant was not a deterrent to resprouting. The management implication is that even decadent shrub fields may be successfully treated with fire.

Table 5--Relationship between fire behavior and heat pulse

Heat pulse	Rate of spread	Flame depth	Flame length	Residence time	Total heat release
	- - - - - - - - - - - Correlation coefficient - - - - - - - - - - -				
Soil	-0.07	0.06	0.09	-0.09	0.27
Stem	-0.14	0.04	-0.02	-0.12	0.22
	- - - - - - - - - - - - - Significance level - - - - - - - - - - - -				
Soil	0.31	0.35	0.26	0.25	0.03
Stem	0.17	0.39	0.45	0.19	0.06

Table 6--Target and achieved fire treatments

Fire treatment	Flame length m		Residence time min		Total heat release mJ/m^2	
	Target	Observed	Target	Observed	Target	Observed
1	0.2-0.5	0.51	1.0	1.7	20	52
2	0.05-0.1	0.21	1.0	4.1	8	20
3	0.5-0.75	1.00	1.0	1.4	40	105
4	1.5-2.0	1.42	0.2	0.6	20	41
5	0.1-0.15	0.28	2.0	4.5	20	44

Plant response to burn treatment was insignificant. The range of fuel loadings tested resulted in fires that killed all above-ground stems but did not kill the below-ground plant parts.

REFERENCES

Bradley, Anne F. 1984. Rhizome morphology, soil distribution, and the potential fire survival of eight woody understory species in western Montana. Missoula, MT: University of Montana. 183 p. Thesis.

Brown, James K. 1976. Estimating shrub biomass from basal stem diameters. Canadian Journal of Forest Research. (6)2: 153-158.

Flinn, Marguerite A.; Pringle, Joan K. 1983. Heat tolerance of rhizomes of several understory species. Canadian Journal of Botany. 61: 452-457.

Hemmer, Dennis M. 1975. Serviceberry: ecology, distribution, and relationships to big game. Missoula, MT: University of Montana. 76 p. Thesis.

Johnston, M.; Woodard, P. 1985. The effect of fire severity level on postfire recovery of hazel and raspberry in east-central Alberta. Canadian Journal of Botany. 3: 672-677.

Kaufman, J. Boone; Martin, Robert E. 1985. Shrub and hardwood response to prescribed burning with varying season, weather, and fuel moisture. In: Symposium, Eighth conference on fire meteorology; 1985 April 29-May 2; Detroit, MI. Washington, DC: Society of American Foresters and American Meteorological Society: 279-286.

Miller, Melanie. 1977. Response of blue huckleberry to prescribed fires in a western Montana larch-fir forest. Res. Pap. INT-188 Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 33 p.

Noste, Nonan V. 1982. Vegetation response to spring and fall burning for wildlife habitat improvement. In: Baumgartner, David M., compiler and ed. Site preparation and fuel management on steep terrain: Proceedings of a symposium; 1982 February 15-17; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension: 125-132.

Pfister, Robert D.; Kovalchik, Robert L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Rothermel, Richard C. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Ryan, Kevin C.; Noste, Nonan V. 1985. Evaluating prescribed fires. In: Proceedings: Symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 230-238.

THE ECOLOGY OF VACCINIUM GLOBULARE:

SEEDLING ESTABLISHMENT AND NUTRITION

Nellie M. Stark

ABSTRACT: Studies of the wild Montana huckleberry (Vaccinium globulare) are in progress to provide the information needed to supply the growing huckleberry industry with a stable supply of fruit. The plant provides an important food supply for wildlife as well. Seed germination in the wild is rare except in unusual years when the temperatures are favorable and when the soil remains constantly moist for a year or more. Water holding capacities of soils that exceed 22 percent are associated with better seed germination and seedling survival. Burial of the seeds by litterfall may reduce field germination. The plants normally reproduce asexually by growth of rhizomes. Container-grown seedlings provided with a special fertilizer in peat moss will produce exceptionally vigorous roots. Large plants that produce good fruit yields have more of most nutrients, including copper and boron, than large non-producing plants. High concentrations of manganese may be detrimental to fruit production. Soils supporting high fruit production in nine out of ten years had significantly more available boron, magnesium, calcium, phosphorus, zinc and total nitrogen than soils supporting plants that bear good fruit crops one out of ten years.

INTRODUCTION

The Montana wild huckleberry (Vaccinium globulare) is a fruit of considerable importance to wildlife and humans. Since the genus is Vaccinium, the plants are actually blueberries, but are called "huckleberries" in Montana in recognition of their exceptional flavor. The fruit is eagerly sought for pies, candies, jam and jellies by a rapidly growing industry.

Huckleberry plants are frequently damaged by desiccation and cold when the tops extend above shallow snow packs during winters with low precipitation, especially at low elevations. Spring frosts often destroy the flowers resulting in poor crops. Occasionally there is failure of pollination in cool and rainy springs. Summer drought is another common problem that diminishes berry production. These natural phenomena, alone or in combination, frequently produce shortages of fruit for both industry and wildlife.

The huckleberry harvest from wild fields in western Montana exceeds 454,000 liters in good years, but may fall below 227,000 liters in poor years (Stark, unpublished). If the huckleberry industry is to continue to develop in Montana, it is essential to find ways of guaranteeing a more stable supply of fruit. Thus, extensive studies of the ecology of huckleberry have been undertaken to provide the information needed to maintain good field berry production for wildlife and human use.

Huckleberry products are being marketed from Montana over much of the United States with plans to expand to international markets. Annual income to Montana from the wild fruit exceeds several million dollars at present.

Three areas of research are being pursued to meet the growing commercial demand for fruit and lessen the adverse impacts of disturbance and diminished food supply for wildlife: the manipulation of wild berry fields to improve production for wildlife, field ecology of the species and the cultivation of berry plants for garden plantings. This paper reports results primarily from the ecological studies.

Much is known about the blueberry family (V. membranaceum, V. myrtillus, V. angustifolium), particularly the commercial blueberry species. Small (1972) described the photosynthetic strategy of bog plants, indicating a high photosynthetic efficiency for V. myrtilloides and a high nitrogen use efficiency. Factors that influence the decline phenomenon in Maine lowbush blueberries (V. angustifolium) were reported by Trevett (1956). Yarborough and others (1986) reported maximum yields of V. angustifolium in Maine of 3,926kg/ha after treatment with 1.83 kg hexazinone/ha. This treatment is presently being tried in Montana. Janke (1968) reported on the ecophysiology of V. myrtillus, emphasizing energy exchange. Pollination strategy and disease problems were described by Batra and Batra (1985), with emphasis on the mummy berry disease, Monilinia sp. Bannister (1980) reported increased winter carbohydrate losses and lower summer carbohydrate gains for species growing in cool, moist climates. High and lowbush blueberries in Michigan were studied by Pritts (1984) for yield component interactions, genetics and biomass partitioning. The ecology of

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Nellie M. Stark is Forest Ecologist with the School of Forestry, University of Montana, Missoula, MT 59812

a closely related species, Vaccinium membranaceum, was studied by Minore and others (1979) for populations occurring in Washington State. The nutritional requirements of the Washington populations of V. membranaceum were reported by Nelson in 1974 and Minore studied the tolerance of the same species to manganese in 1975. Studies of other species of Vaccinium from around the world have little bearing on the Montana species.

Montana has three other species of Vaccinium which are not presently being studied. Van der Kloet (1984) has indicated that the main berry-producing plant in Montana may actually be a large ecotype of V. deliciosum which grows on the Washington coast. The Montana plants are 0.3 to 0.6 m tall and bear fruit ranging in color from black to blue to red. The Montana plants are quite different in appearance to the coastal V. deliciosum, however. Since no verification of the name change has appeared in the literature, I use in this report the name Vaccinium globulare, which is currently accepted as the appropriate scientific name (Stickney 1972). This report is a summary of my progress to date. Technical details including methodology will be published next year.

REPRODUCTIVE CHARACTERISTICS

Seed Germination

Studies of the influence of temperature, pH, seed source and light on the germination of V. globulare seeds have indicated a strong influence of environment on seed germination. In nature, the seeds may germinate, but young plants grown from recently germinated seeds have not been found by any of a number of scientists who frequent the wild berry fields (Stickney 1985). Seed germination may be unsuccessful because of the young seedlings dependence on a constantly moist substrate. In germination tests in the laboratory, plates that became even slightly dry, especially during the early germination phase, failed to produce seedlings. Other evidence of the dependence of young seedlings on moisture came from soil transfer studies. One soil type with a high ash content and associated high water holding capacity (22 percent) supported twice as many seedlings as a soil that is typically less productive and 40 times more seedlings than a soil which supports a good berry crop once in ten years (water holding capacity of 11 percent). One of the soils had been moved from its original location so that the two soils were side by side in the same microclimate.

Seeds germinated poorly in shaded conditions where the exposure to light was less than 1 percent of full sunlight. This type of light exposure is common in the wild because the leaves of the huckleberries and those of Alnus sinuata, a common associate, fall in the autumn after the fruit have fallen to the ground. The result is frequent burial of the fruit and seeds which produces few, weak seedlings that are unable to grow through the autumn accumulation of litter. Overall, germination is three times better with exposure of seeds to light near to 10 percent of full sunlight than at less than 1 percent of full sun.

Surface temperatures of 5 and 30 C produced no seed germination. In spring when germination would normally occur, 5 C temperatures would not be unusual in the field. The 30 C temperature is probably not achieved during the year, except during late summer on extremely open south slopes. Temperatures of 30 C caused accelerated drying of the substrate. The best germination occurred at 20 C (70 percent) with somewhat poorer germination at 10 C (52.6 percent). Germination was reduced at higher soil temperatures. Considering that the seeds would normally germinate during a period when the soil temperatures were between 5 and 8 C, temperature could well be another factor discouraging seed germination in the field.

Good seed germination occurred at pH 4, 5, and 6, which is the normal range for spring surface soil. Soil acidity is not suspected as a factor preventing seed germination.

Fruit pulp does not appear to have any direct inhibitory effect on seed germination, except for the physical burial of the seeds. Seedlings were able to push through the pulp and emerge into the light, but at a greatly reduced rate (3 to 5 percent germination compared to 73 to 83 percent for seeds free of pulp). Burial of seeds by pulp that is not fully decomposed under the snow may account for some germination failure. Germination varies by family and year from 46 percent to 84 percent of normal appearing seeds. Plants produce up to 58 percent aborted seeds, so germination is based on the remaining 42 percent sound appearing seed. Data on wild fruit production have been limited by three years of poor crops, during which fruit production ranged from 0 to 1,600 kg/ha. Considering the extensive cover of other brushy species on the average hectare (25 to 79 percent) and the frequent poor droughty or cold years, the low production is understandable. Yarborough and others (1986) reported 3,926 kg/ha for Maine blueberries in areas with brush control. The Maine fruit are borne in clusters and are more prolific than the Montana species which bears fruit singly. A meter square area in Montana can produce about 580 fruit of V. globulare. Each fruit has about 40 normal-appearing seeds with a germination potential of 42 percent (worst possible case) or a calculated ability to produce on the average 9.744 viable seeds/m^2. This translates to about 97,440,000 potential seedlings per hectare per year. Obviously the seed source is present, yet we did not find the seedlings in nature. Only under closely controlled conditions was it possible to obtain germination in the field. This work agrees with that of Vander Kloet (1976) who concluded that unfavorable soil temperatures and water stress were the main reasons why V. angustifolium was unable to produce a crop of seedlings more than once a century. Both species propagate asexually by rhizomes.

Rooting

One reason why the Montana huckleberry has not been grown commercially to date is the problem of transplanting seedlings from the field. The plants have rhizomes that grow 3 to 8 cm beneath the soil and litter. These rhizomes bear a few fine, weak roots that are almost impossible to excavate intact. Without the roots, the rhizomes must be held in a mist chamber until they can develop new roots, a slow process with a high mortality rate. My recent studies show that the plants will grow well from seeds, although the resulting stock is widely variable in appearance. Seeds placed in a rooting medium of low bulk density, such as peat moss, grow readily and produce extensive, vigorous roots. When grown in open containers, the roots intermingle so extensively that it is difficult to transplant individual seedlings. Plants grown in "supertubes" (conetainers) with peat moss and a special fertilizer supplement produce exceptionally vigorous, compact roots (fig. 1). Tissue culture is presently being used to develop more genetically uniform planting stock. Once the culture methods are perfected, the sprouts will be grown in supertubes to concentrate root development.

Because of the failure of seed germination in the field, new genetic combinations are being formed naturally, but not tested frequently in nature. For this reason, we intend to continue to screen seedlings through seed germination for superior strains that may not yet occur in the field. Testing requires growing the plants in gardens until they reach bearing size. Maintenance of the flavor of the fruit is a high priority. Also, because the plants spread predominately by rhizomes at the rate of about 20 cm per year, the species has probably not reached the extent of its potential range. This is supported by field tests of planted seedlings that are surviving well beyond the species present range.

CARBON AND NUTRIENT ALLOCATION

Plants of Vaccinium globulare were collected from 0.1m^2 subplots in 35 stands covering seven major berry-producing areas in western Montana. Plants varied in size, age and fruit production, but all were from sunny locations. These plants and the soils that they grew in were analyzed for nutrients, fruit production and carbon allocation to determine what conditions appear to correlate well with good growth and berry production. The populations were divided into small plants with no fruit, large plants with no fruit (but adequate water on the site) and large plants with >40g/m^2 of fruit production. This allowed examination of the nutritional conditions favoring fruit production. It also allowed us to examine how the plants partition carbon into specific types of compounds through the aging process.

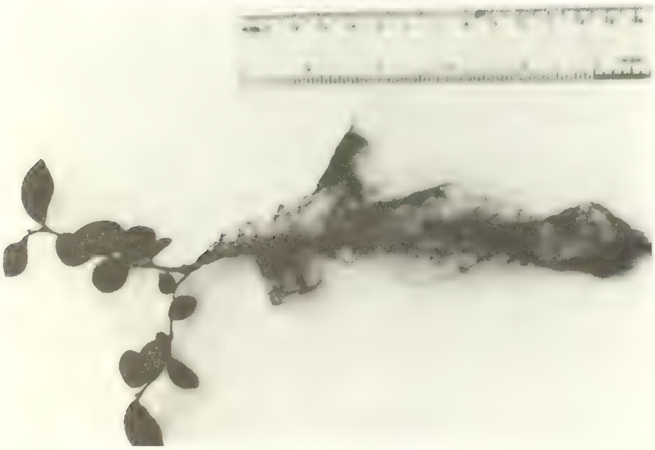

Figure 1--Photograph of root system of a seedling of Vaccinium globulare grown in a super tube.

When data from the entire population were combined and plotted with standard deviation for each nutrient using centric polygrams (regardless of production or size), the nutrient concentrations of leaves, new stems, old stems and rhizomes had large standard deviations, as expected (Stark, in press). In general, the leaves had the highest concentrations of nutrients on a micrograms per gram basis, with new stems, old stems and rhizomes in descending order of total nutrient content. Surprisingly high concentrations of Mn occurred in the leaves, approaching 3,000 ppm, with up to 4,000 ppm Mn in the new stems. Boron concentrations were quite variable in the leaves but highly consistent in all other plant parts.

The nutrient content as mg/m^2 of leaves showed significantly more of most nutrients in the large producing plants except for manganese, silicon, sodium and zinc, which were similar for both large and small plants, regardless of fruit production. New stems appear to function mainly as transport organs, with few significant differences in the nutrient content per meter square. Old stems are major nutrient sinks with significantly more of all nutrients except manganese and zinc in the large producing plants than in the large or small non-producing plants. Rhizomes held less total nutrient per meter square than the old stems or leaves, but more than the new stems. Rhizomes tended to have significantly more nutrient in the large producing plants per meter square, compared to the large and small non-producing plants. Fine roots proved to be nutrient sinks also, storing considerable amounts of nutrients per gram, but constituting an extremely small biomass on an area basis. Thus, plants that are able to produce good fruit crops are generally larger ($\bar{X}$ of 2,441 g dry weight/m^2 compared to non-producing plants, 790 to 1,986g/m^2) and have the largest total nutrient storage in nearly all compartments except the new stems.

This raises the question of how the high producing plants are able to accumulate so much more nutrients and biomass. One hypothesis is that lack of water stress would allow better nutrient uptake and availability and might result in better mycorrhizal formation.

It is also valuable to look at the concentration of nutrients in the individual plant parts as micrograms per gram expressed as per gram of total plant weight. This method of expression removes the problem of differences in the relative weight of the various plant parts. When data were expressed in this manner, leaves of the large producing and large and small non-producing plants showed little significant differences in nutrient concentration. This means that it takes so much nutrient to produce a gram of leaf, regardless of how many leaves there are per meter square. Only boron and copper showed significantly higher concentrations in the high producing plants, suggesting that these should be tested as possibly limiting factors to production. Differences in the amount of total copper remained important per gram of total plant for the old stems of the high producing plants. Thus, old stems function as reservoirs for nutrients and are a good tissue to examine for possible nutrient deficiencies. Rhizomes had surprisingly high concentrations of iron, phosphorus and aluminum in the young non-producing plants, suggesting that these nutrients are important to young growing plants.

Data of this type (µg/g of plant) from the whole plant are useful when formulating fertilizer that will meet the growth demands of plants in different stages of development and for possibly stimulating non-producing large plants to produce. On the basis of whole plants, the large producing plants had the most aluminum, boron, calcium, copper, potassium and phosphorus, while small non-producing plants had the most iron and sodium. Large non-producing plants had significantly low levels of aluminum, copper, iron, potassium, sodium and phosphorus. This suggests that fertilizers that would supplement these available soil nutrients may, in the absence of other stresses, stimulate fruit production. This hypothesis will be tested in the near future. Although sodium is not known to be an essential nutrient to growth of these plants, it is thought to be important in maintaining osmotic potentials needed to bring in water that is essential to cell expansion.

Certain plant parts act as sinks for different nutrients. Nitrogen, boron, magnesium and silica were stored in large amounts in the flowers and leaves, while roots stored aluminum and iron. Roots stored the most copper and iron. Significant amounts of potassium occurred in the flowers, and old stems stored considerable copper and zinc. Work by Ingestad (1973) showed that V. vitis-idaea and V. myrtilloides had low potassium requirements and rapid calcium uptake, compared to other woody species of forest plants. Both nitrate and ammonium forms were used by these species of Vaccinium.

Xylem Sap Analysis

The field technology for the extraction and analysis of xylem sap from trees has been adapted to shrubs as a means of evaluating the nutrient status of shrubs (Stark and others 1985). The main modification for shrubs is that the tygon tubing that is attached to the cut end of the branch that extends outside of the pressure chamber is fastened to a small vial and the sap is allowed to flow from the branch directly into the vial.

Results of xylem sap analysis from high production plants showed significantly higher levels of boron, iron, magnesium, sodium and nitrogen than xylem sap from plants in areas that rarely produce fruit. Climatic factors and nutritional factors are thought to interact to make a particular site conducive to high fruit production.

ORGANIC COMPOSITION

Large producing plants had significantly more total nitrogen, total non-structural carbohydrates, caloric content and ash content on a meter square basis. Large non-producing plants had more cellulose, but nearly the same amounts of tannin and lignin as the large producing whole plants. Small non-producing plants had a third of the total nitrogen that occurred in the large producing plants, and about a third of the total nitrogen. On a concentration basis, large producing plants had 17,027 ppm nitrogen while small non-producing plants had 14,340 ppm in the foliage.

The lignin content of the old stems and rhizomes was high compared to other plant components. The tannin content of the leaves was higher than that in other plant parts. The tannin content of foliage does not appear to be an effective deterrent to herbivory because the leaves are readily eaten by several insects and other higher animals. Tent caterpillars eat the foliage readily.

SOILS

Soils from sites with high fruit production had significantly higher concentrations of boron, calcium, magnesium, phosphorus, zinc, and total nitrogen than soils from non-producing sites. This trend for higher soil organic matter and available nutrients has been found consistently on sites with high fruit production, prompting the conclusion that good fruit production is most likely to occur on the more fertile soils and those with more organic matter and available soil moisture.

The results of these and other studies have provided considerable assistance in the development of a commercial huckleberry growth strategy.

REFERENCES

Bannister, P. 1980. The nonstructural carbohydrate contents of ericaceous shrubs from Scotland, UK and Austria. Acta Oecologica Plantarum 1: 275-292.

Batra, L.; and Batra, S.W. 1985. Floral mimicry induced by mummyberry fungus exploits hosts pollinators as vectors. Science 228:1011-1012.

Ingestad, T. 1973. Mineral nutrient requirements of Vaccinium vitis-idaea and Vaccinium myrtillus. Physiologia Plantarum 29:239-246.

Janke, R. A. 1968. The ecology of Vaccinium myrtillus using concepts of productivity, energy exchange and transpiration resistance. Boulder, CO: University of Colorado. Ph.D. dissertation, American Journal of Botany 57:1051-1054.

Minore, D. 1975. Comparative tolerance of lodgepole pine and thin-leaved huckleberry to boron and manganese. Res. Note PNW-253. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 6 p.

Minore, D.; Smart, A. W.; Dubrasich, M. 1979. Huckleberry Ecology and Management Research In The Pacific Northwest. Gen. Tech. Report PNW-93. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 50 p.

Nelson, E. A. 1974. Greenhouse and field fertilization of thin-leaved huckleberry. Res. Note PNW-236. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 13 p.

Pritts, M. P. 1984. Environmental physiology and influence on yield component interactions and biomass partitioning in wild populations of highbush and lowbush blueberries. East Lansing, MI: Michigan State University, 94 p. Dissertation.

Small, E. 1972. Photosynthetic rate in relation to nitrogen recycling as an adaptation to nutrient deficiency in peatbog plants. Canadian Journal of Botany 50:2227-2233.

Stark, N.; Spitzner, C.; and Essig, D. 1985. Xylem sap analysis for determining the nutritional status of trees: Pseudotsuga menziesii. Canadian Journal of Forest Research, 15:429-437.

Stickney, P. 1972. Field Identification of Western Montana Vaccinium. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 14 p. Processed report.

Stickney, P. USDA Forest Service [Personal Communication] Intermountain Forest and Range Experiment Station, Missoula, MT. 1985.

Trevett, M. F. 1956. Observations on the decline and rehabilitation of lowbush blueberry fields. Publication C26. Orono, ME: University of Maine, Agricultural Experiment Station, 21 p.

Vander Kloet, S. 1979. A comparison of the dispersal and seedling establishment of Vaccinium angustifolium (lowbush blueberry) in Leeds County, Ontario and Pictou County, Nova Scotia. The Canadian Field Naturalist. 90:177-180.

Vander Kloet, S. 1984. [Personal Communication] 1984. Acadia University, Wolfeville, Nova Scotia.

Yarborough, D. E.; Hanchar, J. J.; Skinner, S. P.; Ismail, A. A. 1985. Weed response, yield and economics of hexazinone and nitrogen in lowbush blueberry production. Weed Science 34:723-729.

COMPARATIVE GROWTH OF FOUR SHRUB SPECIES IN A NATIVE DESERT SOIL AND AN AMENDED NON-CALCAREOUS SOIL AND SOME UNSOLVED PROBLEMS IN MINERAL NUTRITION OF DESERT SHRUBS

Arthur Wallace

ABSTRACT: Four desert shrub species native to the northern Mojave Desert were grown in a non-saline but calcareous soil from that desert and in a non-calcareous non-saline soil for four months with and without gypsum and lime amendments. The species were Larrea tridentata, Ambrosia dumosa, Ceratoides lanata, and Grayia spinosa. Growth for three species was higher in the non-calcareous soil than in the desert soil which is from an area where all four species grow naturally. The one species that did not grow better in the non-calcareous soil was one that is a high accumulator of K. All four species responded postively to Ca and Mg sulfates applied to the non-calcareous soil. Calcium and Mg carbonates applied to the non-calcareous soil depressed growth of L. tridentata, while only Mg carbonate decreased that of A. dumosa and C. lanata. Both carbonates improved growth of G. spinosa, although the increases were not different at the 0.05 level of significance. Adaptation of these four species to desert conditions may be due largely to factors other than soil characteristics. Among the unsolved nutritional problems of desert shrubs are those related to differential accumulation and partitioning of cations, especially Na, for different species that grow side by side at the same locations. Cation-anion ratios in these plants are of considerable interest in relationship to micronutrients.

INTRODUCTION

Most desert-plant species grow in soil which is highly calcareous and often in soil which is also high in gypsum. The purpose of this study was to determine if four representative species from the northern Mojave Desert are obligate for $CaCO_3$, $MgCO_3$, or gypsum. The purpose was not to explain the mineral relationships of the desert plants used, although the study contributes to that also. Mineral composition of these species has been reported (Romney and others 1973; Wallace and others 1972). The comparative mineral nutrition of native plants is a subject about which more information would be useful, especially for desert shrubs (Gerloff 1963). Species with greatly differing nutrient requirements often grow side by side.

MATERIALS AND METHODS

Single Larrea tridentata (Ses. and Moc.) seedlings, Ambrosia dumosa (Gray) seedlings, Ceratoides lanata (Pursh) Moq. cuttings, and Grayia spinosa (Hook.) Moq. cuttings were grown in pots of soil in a glasshouse. The G. spinosa plants were chilled at 5C one week before beginning the test so that their growth would be normal (Wallace and others 1970). Soil used was either nearly neutral Yolo loam (a Xerorthents from California) or a highly calcareous soil (a Durargid from Mercury, Nevada). The Yolo loam was amended to give various treatments: 2% $CaCO_3$, ½% $MgCO_3$, ½% $CaSO_4$, ½% $MgSO_4$, 2% $CaCO_3$ + ½% $MgCO_3$, 2% $CaCO_3$ + ½% $MgCO_3$ + ½% $CaSO_4$, 2% $CaCO_3$ + ½% $MgCO_3$ + ½% $CaSO_4$ + ½% $MgSO_4$. Plants were grown in 1000-g quantities of these soils for four months (January through April). The glasshouse temperature ranged from 22 to 28C daytime and 15 to 20C night. Nitrogen was applied five times during the test, and sufficient N as NH_4NO_3 was added each time to give 15 mg N kg^{-1} soil. Once each week a solution of 10^{-3}M KH_2PO_4 was used as an irrigating solution. The plants were irrigated otherwise with distilled-deionized water as needed to maintain soil moisture near -0.03 MPa. Pots had bottom drain holes so the $CaSO_4$ in various treatments was renewed during the test. Each treatment was in triplicate. At the end of the four months the shoots were cut 1 cm above the soil line and washed with 1/10 N HCl and then with distilled-deionized water. Dry weights were determined, and plants were prepared for mineral analyses by optical emission spectrometry (Alexander and McAnulty 1981).

RESULTS AND DISCUSSION

When grown in the Yolo loam soil, L. tridentata responded positively to $CaSO_4$ and slightly negatively to the $CaCO_3$ and $MgCO_3$ (table 1). Plants with $MgCO_3$ tended to be slightly chlorophyll deficient; but Zn, Cu, Fe, and Mn levels did not seem to be decreased. Molybdenum was increased by some liming materials as is well known (Evans and others 1951). Magnesium levels were increased by the Mg-containing materials. $MgCO_3$ alone decreased the P

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Arthur Wallace is Research Plant Physiologist, Laboratory of Biomedical and Environmental Sciences, University of California at Los Angeles, 900 Veteran Avenue, Los Angeles, CA 90024-1786, operated for the U.S. Department of Energy by the University of California under contract No. DE-AC03-76-SF00012.

contents of plants. L. tridentata plants grown in the desert soil were much smaller than those grown in the Yolo loam soil, particularly when carbonates had not been added to the Yolo soil.

All A. dumosa grown in $MgCO_3$ had chlorophyll-deficient leaves in varying degrees and yields (table 1) were related to this phenomenon. Growth was increased slightly by Ca-containing amendments, but not significantly in the test. Magnesium concentrations were increased by Mg amendments. Phosphorus concentrations were decreased with liming materials; $MgCO_3$ caused greater decreases than did $CaCO_3$. Zinc and Mn concentrations of these plants were decreased by the liming materials, but liming had no effect on Fe concentrations.

Highest yields of C. lanata were with $CaSO_4$ (table 1). Yields with $MgCO_3$ were generally decreased, but the leaves showed no chlorophyll deficiency. The Mg materials increased the Mg concentrations of leaves and simultaneously decreased those of Ca. Mg had more effect than Ca on Ca concentrations of leaves, but the Mg effect was negative. Liming materials decreased P concentrations of leaves. They also decreased Zn, Cu, and Mn in this species, but not Fe concentrations of leaves. Yields of C. lanata grown in the desert soil were like those of the control Yolo soil in contrast to L. tridenata and A. dumosa.

G. spinosa responded favorably to CaSO, but not to $CaCO_3$ or $MgSO_4$ (table 1). The latter two, however,

Table 1--Yields of shoots and mineral composition of leaves of plants grown with various lime materials in Yolo loam soil

Treatment[1]	L. tridentata	A. dumosa	C. lanata	G. spinosa	L. tridentata	A. dumosa	C. lanata	G. spinosa	L. tridentata	A. dumosa	C. lanata	G. spinosa
	dry weight yield				Ca				Mg			
	mg plant^{-1}				% of dry weight				% of dry weight			
Control	549	814	1033	436	1.35	1.99	1.13	0.48	0.24	0.44	0.40	0.69
2% $CaCO_3$	284	960	940	568	1.32	1.97	1.04	0.77	0.25	0.39	0.35	0.75
1/2% $MgCO_3$	240	427	644	546	1.26	1.21	0.93	0.65	0.48	0.69	0.56	1.33
1/2% $CaSO_4$	919	1118	1426	887	1.48	1.95	1.21	0.92	0.22	0.33	0.41	0.79
1/2% $MgSO_4$	482	1152	1245	761	1.19	1.40	0.86	0.59	0.41	0.64	0.58	0.85
$CaCO_3$ + $MgCO_3$	398	429	765	369	1.11	1.15	1.02	0.65	0.45	0.63	0.58	1.18
$CaCO_3$ + $MgCO_3$ + $CaSO_4$	303	397	824	652	1.59	1.45	1.11	0.58	0.42	0.64	0.55	1.10
$CaCO_3$ + $MgCO_3$ + $CaSO_4$ + $MgSO_4$	358	370	1295	800	1.23	1.20	0.92	0.58	0.49	0.80	0.69	1.09
Nevada desert soil	133	368	952	463	1.53	2.51	1.47	1.36	0.35	0.59	0.49	0.74
LSD 0.05	253	352	510	370	0.25	0.47	0.20	0.55	0.09	0.12	0.08	0.25
	P				Zn				Cu			
	% of dry weight				mg kg^{-1}				mg kg^{-1}			
Control	0.39	0.57	0.96	2.64	39	71	52	109	6	7.6	10.0	35
2% $CaCO_3$	0.32	0.45	0.35	1.07	32	40	38	38	8	6.0	7.8	19
1/2% $MgCO_3$	0.26	0.35	0.31	0.77	34	45	36	50	7	8.0	8.3	25
1/2% $CaSO_4$	0.37	0.62	0.93	2.37	51	68	53	107	7	7.6	11.7	44
1/2% $MgSO_4$	0.38	0.54	1.10	2.11	47	62	66	88	6	7.0	12.0	35
$CaCO_3$ + $MgCO_3$	0.30	0.46	0.35	0.81	42	30	37	43	10	8.7	8.6	19
$CaCO_3$ + $MgCO_3$ + $CaSO_4$	0.44	0.32	0.32	0.51	48	39	37	43	10	9.0	7.3	16
$CaCO_3$ + $MgCO_3$ + $CaSO_4$ + $MgSO_4$	0.37	0.20	0.39	0.52	38	44	34	48	16	8.2	7.7	16
Nevada desert soil	0.25	0.17	0.26	0.30	51	65	38	46	3	1.7	1.8	3
LSD 0.05	0.07	0.06	0.12	0.41	11	11	16	25	5	3.6	1.7	10
	Fe				Mn				Mo			
	mg kg^{-1}				mg kg^{-1}				mg kg^{-1}			
Control	124	63	46	38	28	180	85	85	1.4	1.0	1.3	10.6
2% $CaCO_3$	95	61	39	30	26	55	43	47	8.1	3.7	3.5	12.0
1/2% $MgCO_3$	186	77	49	40	37	87	47	108	7.0	2.3	2.0	11.3
1/2% $CaSO_4$	124	61	45	35	23	160	102	172	0.8	0.8	0.6	3.7
1/2% $MgSO_4$	194	60	55	53	22	166	176	94	0.9	1.2	0.6	3.3
$CaCO_3$ + $MgCO_3$	101	63	48	44	28	57	33	51	5.0	1.3	2.6	8.5
$CaCO_3$ + $MgCO_3$ + $CaSO_4$	107	81	44	27	37	81	48	57	1.0	0.5	0.5	4.3
$CaCO_3$ + $MgCO_3$ + $CaSO_4$ + $MgSO_4$	113	68	50	33	72	79	49	78	0.9	0.9	0.7	3.8
Nevada desert soil	272	81	45	28	29	44	17	9	0.7	0.9	0.5	1.8
LSD 0.05	57	ns	ns	ns	20	35	42	37	2.5	0.9	1.1	2.6

[1] Concentrations of each amendment was similar in the combinations to those for single applications.

did not decrease growth. Calcium and Mg treatments increased Ca and Mg in leaves, respectively; but there was no evidence of an inverse relationship between the two elements in contrast to some of the other plants. Phosphorus levels were high in leaves, but were decreased by liming materials. Zinc and Ca were decreased by the liming materials. The Cu content of G. spinosa leaves was considerably higher than of the other two species. Manganese was decreased by $CaCO_3$, but not by $MgCO_3$. Again, the yields were not decreased for the plants growing in the desert soil.

None of the four plant species seemed to have a lime requirement, even though they normally grow in calcareous soil. All four of the species seemed to respond to $CaSO_4$ (gypsum), but only two were statistically significant. More study is needed to determine if gypsum at a given level is an absolute requirement of these species or if they have a high requirement for S.

SOME UNSOLVED PROBLEMS IN MINERAL NUTRITION OF DESERT PLANTS

In addition to the problems discussed above concerning the obligate nature of desert shrubs for specific soil types, such as high lime, gypsum, saline or sodic or others, there are other questions of interest for which answers have not been obtained. Among these are those related to large differences in cation accumulation for species growing in close proximity to each other (table 2). G. spinosa is an accumulator of K, and it grows close to Lycium andersonii, which is a marked accumulator of Ca. Mirabilis pudica strongly accumulates Mg compared with other species with which it is associated. Atriplex confertifolia accumulates considerable Na while growing close to species which do not. At site 22, plant leaves accumulated little Na, and 58% of the cation sum in G. spinosa was K, while it was only 5% in M. pudica. The cation sum varied considerably among species. One species of Lycium accumulated considerable Na in leaves, while another did not. Acamptopappus shockleyi ordinarily grows in bare soil between shrub clumps where N is poorly available. The leaf analysis consistently indicates lower N and higher Si concentrations than for some species growing in clumps. In fact, the Si in this species approaches that for the grass species Oryzopsis hymenoides shown in table 2.

Many possible research projects are indicated in these sample data. Chloride analyses were not obtained for these samples and would, with P, give a more complete picture for anions. Some of the problems have been studied in part. In one study, three of the species were grown in solution culture with and without Cl, and cation-anion ratios were determined (Wallace and others 1974). With A. confertifolia and A. hymenlytra in the whole plant, cation uptake greatly exceeded anion uptake which implies that protons are excreted to the soil and that the plants would contain higher levels of organic acids. This characteristic is indicative of Fe efficiency (Romheld and Marschner 1984; Wallace and others 1968). (See Nelson and Jolley, these proceedings.) In L andersonii, Ca was less available than for soil, and from some of the solutions anion uptake equaled or exceeded cation

Table 2--Cation and some anion concentrations in leaves. Some shrub and other plant species growing in close proximity to each other at the Nevada Test Site (Adapted from Romney and others 1973)

Species	Na	K	Ca	Mg	Cation sum	N	Si
			me $100\ g^{-1}$ dry weight				
			from site 22				
Ceratoides lanata	1	83	134	43	261	254	10
Grayia spinosa	7	302	89	121	519	234	5
Larrea tridentata	1	68	113	16	197	222	14
Lycium andersonii	1	86	458	75	620	290	7
Mirabilis pudica	0	26	248	198	504	212	11
Oryzopsis hymenoides	1	80	41	24	145	171	119
			from site 51				
Atriplex confertifolia	167	188	216	66	637	96	10
Grayia spinosa	72	204	115	97	488	155	3
Larrea tridentata	1	62	65	15	143	163	9
Lycium andersonii	7	105	482	81	675	179	7
Lycium pallidum	47	81	206	147	481	126	10
			one species from two different sites				
Acamptopappus shockleyi	6	106	87	52	251	186	64
Acamptopappus shockleyi	8	98	63	66	235	166	55

uptake. This implies that the biochemistry of roots may need to split H_2O to yield H^+ and OH^- with the latter metabolized (Wallace and Wallace 1984) for Fe to become available, but this has never been proved as yet.

Another species of Atriplex (canescens) accumulates Na in roots, but translocates very little to shoots (Wallace and others 1973b). The mechanisms for such partitioning have not been elucidated. The three species of Lycium found at the Nevada test site differ greatly in their responses to Na, and one (L. shockleyi) grows only in some saline habitats (Ashcroft and Wallace 1976). When grown in solution culture, cation ratios exceeded anion ratios for all species, although only moderately. Studies of proton release, Fe uptake, organic acid metabolism, and other characteristics are indicated for all these species. Artemisa tridentata appears to be a species in which anion uptake exceeds cation uptake (Wallace and others 1973a) and would be a subject of interesting studies, especially for Fe relations.

REFERENCES

Alexander, George V.; McAnulty, Leon T. 1981. Multielement analysis of plant-related tissues and fluids by optical emission spectrometry. Journal of Plant Nutrition 3: 51-59.

Ashcroft, Rulon T.; Wallace, Arthur. 1976. Sodium relations in desert plants: 5. Cation balance when grown in solution culture and in the field in three species of Lycium from the Northern Mojave Desert. Soil Science 122: 48-51.

El-Ghonemy, Ali A.; Wallace, Arthur; and Romney, Evan M. 1978. Nutrient concentrations in the natural vegetation of the Mojave Desert. Soil Science 126: 219-229.

Evans, Harold J.; Purvis, Ernest R.; and Bear, Firman E. 1951. Effect of soil reaction on availability of molybdenum. Soil Science 71: 117-124.

Gerloff, G. C. 1963. Comparative mineral nutrition of plants. Annual Review Plant Physiology 14: 107-124.

Romheld, Volker; Marschner, Horst. 1984. Plant-induced pH changes in the rhizosphere of "Fe-efficient" and "Fe-inefficient" soybean and corn cultivars. Journal of Plant Nutrition 7: 623-630.

Romney, Evan M.; Hale, Verle Q.; Wallace, Arthur; Lunt, Owen R.; Childress, James D.; Kaaz, Howard; Alexander, George V.; Kinnear, Jean E. 1973. Some characteristics of soil and perennial vegetation in Northern Mojave Desert areas of the Nevada Test Site. UCLA #12-916.

Wallace, Arthur; Frolich, Edward F.; El-Gazzar, Azzim. 1968. Root excretions in iron-deficient tobacco plants and possible effects on iron nutrition. International Atomic Energy symposium isotopes and radiation in soil organic-matter studies. Vienna 1968, pp. 385-396.

Wallace, Arthur; Mueller, Roland T.; Romney, Evan M. 1973b. Sodium relations in desert plants: 2. Distribution of cations in plant parts of three different species of Atriplex. Soil Science 115: 390-394.

Wallace, Arthur; Romney, Evan M.; Ashcroft, Rulon T. 1970. Soil temperature effects on growth of seedlings of some shrub species which grow in the transitional area between the Mojave and Great Basin Deserts. BioScience 20: 158-159.

Wallace, Arthur; Romney, Evan M.; Cha, Jong W. 1974. Sodium relations in desert plants: 3. Cation-anion relationships in three species which accumulate high levels of cations in leaves. Soil Science 118: 397-401.

Wallace, Arthur; Romney, Evan M. eds. 1972. Radioecology and ecophysiology of desert plants at the Nevada Test Site. USAEC Monograph TID-25954, 439 pp.

Wallace, Arthur; Romney, Evan M.; Hale, Verle Q. 1973a. Sodium relations in desert plants: 1. Cation contents of some plant species from the Mojave and Great Basin Deserts. Soil Science 115: 284-287.

Wallace, Arthur; Wallace, Garn A. 1984. Cation-anion uptake balance and proton efflux in plant efficiency for iron. Journal of Plant Nutrition 7: 847-852.

PHYSIOLOGICAL CHANGES IN *CHRYSOTHAMNUS NAUSEOSUS* IN RELATION TO RUBBER AND RESIN PRODUCTION

D. J. Weber, D. F. Hegerhorst, R. B. Bhat, T. D. Davis, and E. D. McArthur

ABSTRACT: Of particular interest in *Chrysothamnus nauseosus* (rubber rabbitbrush) is the presence of natural rubber that has potential commercial value. The factors that regulate rubber or resin production are of special interest because of the potential of increasing the rubber content. Rubber rabbitbrush, maintained under irrigation, exhibits relatively high rates of net photosynthesis for a woody species throughout the growing season. Net photosynthesis is generally highest during cool morning hours (0900-1000 h) and is not light saturated at light levels equivalent to full sun. The changes in rubber and resin content in new growth, one-year-old tissue, and several-years-old tissue were followed during the growing season in *Chrysothamnus nauseosus* ssp. *turbinatus* and *Chrysothamnus nauseosus* ssp. *hololeucus*. The top of the plants contained the highest level of resin and the lowest amount of rubber. In contrast, the highest rubber content and lowest resin content were in the older stems near the soil level. The negative correlation between the rubber and resin was high ($r^2 = 0.64$, $p = 0.03$). When the rubber and resin contents were followed through the growing season, the highest rubber content and lowest resin content occurred during August. In contrast, the highest resin and lowest rubber occurred in the spring. The negative correlation between rubber and resin in one-year-old stems of ssp. *turbinatus* was high ($r^2 = 0.76$, $p = 0.004$). A bioregulator treatment (paclobutrazol) significantly ($p < .05$) increased resin content and decreased rubber content.

INTRODUCTION

Chrysothamnus nauseosus (rubber rabbitbrush) is widely distributed in the western United States (Anderson 1986). Subspecies of *C. nauseosus* occur from Mexico to Canada, from sea level to 3,000 m above sea level and on disturbed sites and saline soils (McArthur and others 1979; McArthur 1984). Rubber rabbitbrush is a diversified species that survives well under conditions that cause considerable stress to most plants. It is of particular interest that rubber rabbitbrush contains natural rubber that may have commercial value (Hall and Goodspeed 1919; Weber and others 1985; Ostler and others 1986). The factors that regulate the production of rubber in rabbitbrush are not well understood. This paper reviews progress we have made in that area and presents new data on physiological response to stress conditions.

PHOTOSYNTHETIC CHARACTERISTICS

Rubber rabbitbrush fixes carbon dioxide by the C_3 pathway as indicated by its C_{13}/C_{14} ratios (Smith 1987). Yet this plant exhibits relatively high rates of net photosynthesis (Pn) as compared to other woody C_3 plants. On both leaf area and dry weight bases, the rate of Pn of *C. nauseosus* ssp. *albicaulis* is similar to the C_4 desert shrub *Atriplex canescens*. The carbon dioxide fixing enzyme, RuBP carboxylase, and intercellular CO_2 contents of rubber rabbitbrush are similar to those found in most C_3 crop species (Davis and others 1985). An interesting ecophysiological aspect of rubber rabbitbrush Pn is that photosynthesis is not light saturated at light levels that are equivalent to full sun, perhaps due to the presence of leaf pubescence. This may be a useful, adaptive characteristic for a plant that exists in a desert environment with high light intensity. It has been reported that pubescence on leaves of desert plants reduces the light absorbance resulting in reduced heart loads and lower leaf temperatures (Ehleringer and Bjorkman 1978; Ehleringer and Mooney 1978). Rubber rabbitbrush is capable of maintaining high Pn and high stomatal conductance under well-watered conditions, which results in high rates of dry matter accumulation per unit of biomass (Davis and others 1985; Davis 1987). Rates of rubber rabbitbrush Pn are generally highest during cool morning hours (between about 0900 and 1000 hrs). Pn declines considerably during mid-day hours on hot summer days, probably due to partial stomatal closure (Davis 1987). Biomass studies by McKell and Van Epps (1980) reported that individual rubber rabbitbrush plants that had been clipped and allowed to grow for 2 years yielded average values of 5,670 g per year. Hall and Goodspeed (1919) reported an average growth rate for rubber rabbitbrush of 3,345 to 3,799 g per year in natural populations.

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D. J. Weber is Professor, D. F. Hegerhorst is graduate student, and R. B. Bhat is Research Associate, Department of Botany and Range Science, Brigham Young University, Provo, UT; T. D. Davis is Associate Professor, Department of Agronomy and Horticulture, Brigham Young University, Provo, UT; E. D. McArthur is Supervisory Research Geneticist, Shrub Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

RUBBER AND RESIN CONTENT

Rubber and resin contents of Chrysothamnus were first surveyed by Hall and Goodspeed in 1919. They reported an average rubber content of 1.7% from 140 different samples. They found two subspecies that had a rubber content of 6% (Hall and Goodspeed 1919). In 1982, Ostler and others (1986) made a number of new collections of rabbitbrush and found populations with 6.5% rubber. In 1984, Hegerhorst and others (1987c) made a number of collections from natural populations of rubber rabbitbrush and found that C. nauseosus ssp. turbinatus populations contained 7% rubber.

The resin content of rubber rabbitbrush is of significance because of its potential value as a hydrocarbon source, as potential insecticides, fungicides, and nematocides, and as a chemical feedstock for chemical companies. Buchannon and others (1978) evaluated over 100 plant species as potential hydrocarbon crops and both rubber rabbitbrush and its composite family relative, guayule, rated high. Rubber rabbitbrush had a slightly higher hydrocarbon rating with a value of 11.5%. Natural insecticides from rubber rabbitbrush have been reported by Bohlmann and others (1979a, 1979b), Rose and Jermy (1980), and Maugh (1982), and may have some commercial value.

THE GROWING SEASON STUDY

In 1919 Hall and Goodspeed reported that rubber in rubber rabbitbrush was located in older wood. Hegerhorst and others (1987c) recently analyzed the rubber and resin content from the top to the bottom of individual plants of C. nauseosus ssp. turbinatus (Jones) Hall & Clem (high rubber content about 5-7%) and ssp. hololeucus (Gray) Hall & Clem (low rubber content about 1.5%). The rubber and resin were determined by the method of Hegerhorst and others (1987c). They found that the highest resin content and the lowest rubber content were in the leaves and new shoots of the plant (fig. 1). In contrast, the highest rubber content was in the older stems near the soil

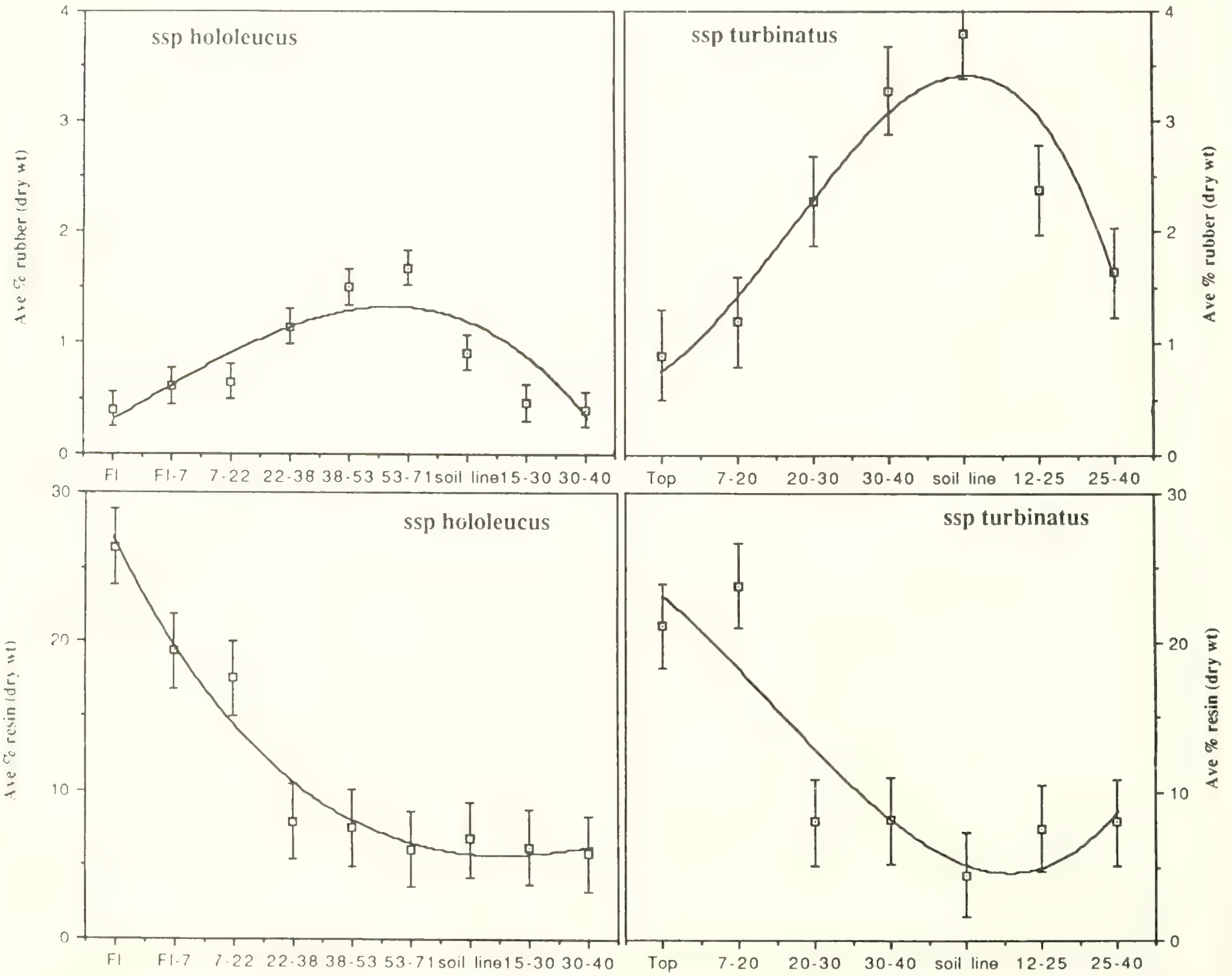

Figure 1--Average percent resin and rubber from top to bottom of C. nauseosus ssp. turbinatus (right) and C. nauseosus ssp. hololeucus (left). Vertical lines represent standard error bars (Hegerhorst and others 1987b).

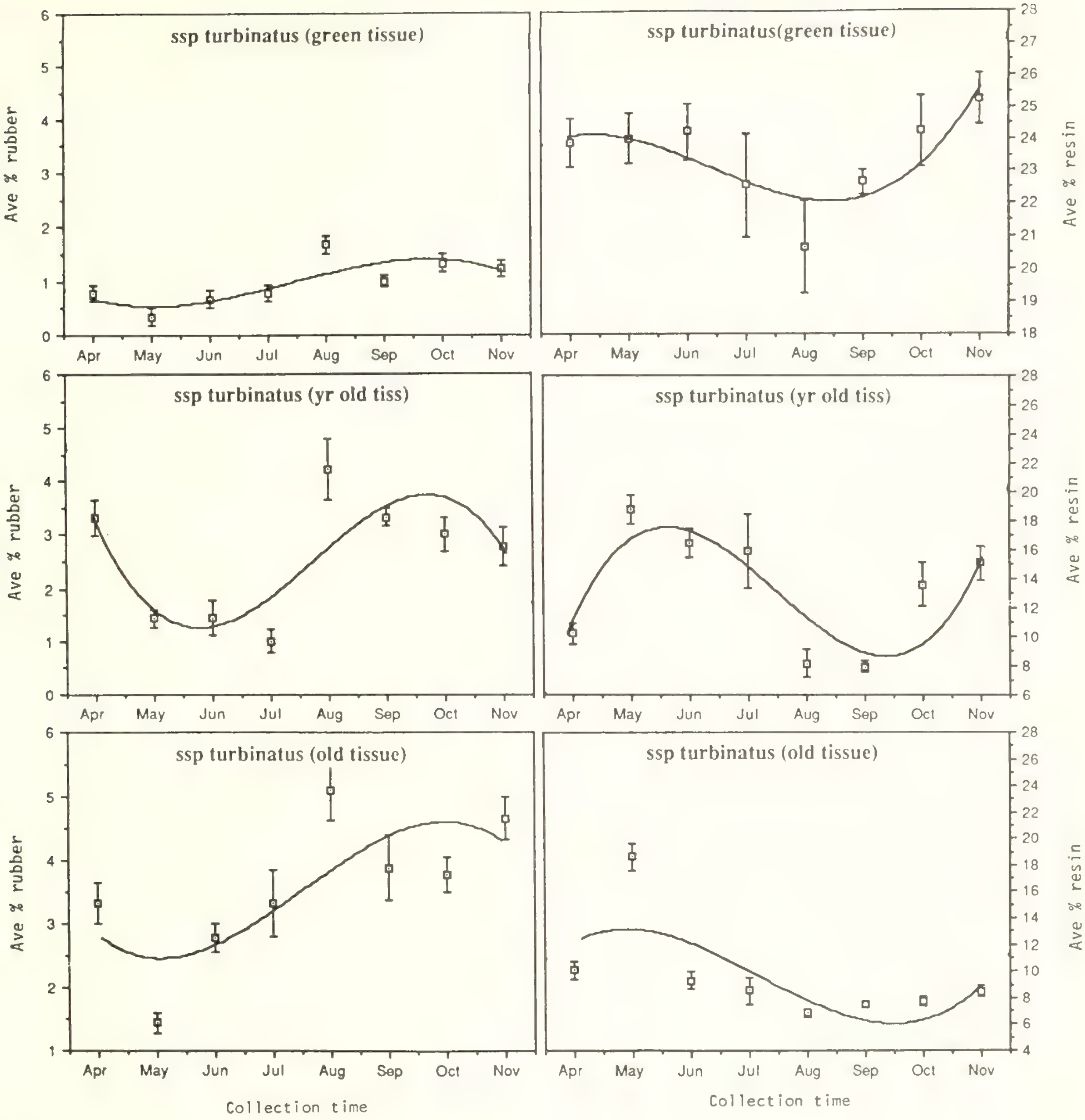

Figure 2--The average percent rubber and average percent resin in green tissue, year-old tissue, and several-years-old tissue of C. nauseosus ssp. turbinatus during the growing season at Goshen, Utah. Vertical lines represent standard error bars (Hegerhorst and others 1987b).

level. The rubber content was also fairly high in the upper roots but dropped off rapidly with increasing depth in the soil (fig. 1). The negative correlation between rubber and resin was strong ($r^2 = 0.64$, $p = 0.03$).

Changes During the Growing Season

Tissue samples of new growth, one-year-old growth, and several-year-old growth were taken monthly from the two sympatric subspecies turbinatus and hololeucus growing near Goshen, Utah. The tissue was ground with a motorized steel mortar and pestle, using liquid nitrogen to freeze the tissue. After grinding, the tissue was stored in a freezer until analyses. The ground tissue was extracted for rubber and resin using the method of Hegerhorst and others (1987c).

The highest content of rubber and lowest resin content in turbinatus occurred in August, whereas the highest resin and lowest rubber content occurred in the spring (fig. 2). In contrast,

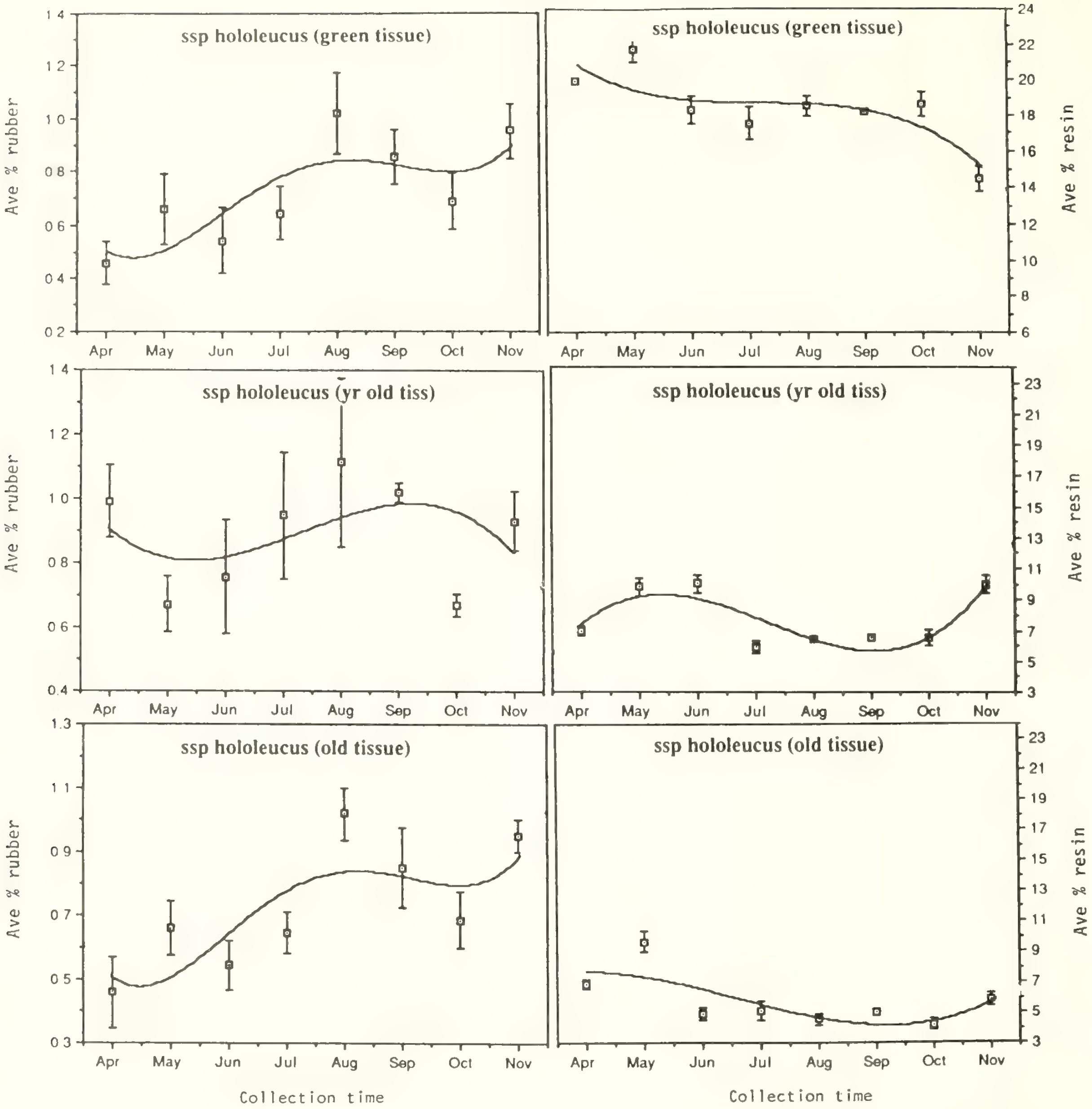

Figure 3--The average percent rubber and average percent resin in green tissue, year-old tissue and several-years-old tissue of C. nauseosus ssp. hololeucus during the growing season at Goshen, Utah. Vertical lines represent standard error bars (Hegerhorst and others 1987b).

guayule has the highest rubber content in the winter (Foster and others 1983; Bucks and others 1986). The negative correlation between rubber and resin was very high (r^2 = 0.76, p = 0.004). A similar rubber and resin pattern was present in ssp. hololeucus (fig.3) except the negative correlation was not as high. Also rubber content was considerably lower in ssp. hololeucus as compared to ssp. turbinatus.

The summer months of June, July, and August are periods of high temperature and low rainfall for the Goshen site (fig. 4) (Stevens and others 1983). This presumably would be a period of high water stress for plants growing on the site. Ostler and others (1986) have analyzed the environmental conditions at different collection sites of rubber rabbitbrush and concluded that stressful conditions were correlated with higher rubber content. The results of Hegerhorst and others (1978b) also suggest a strong correlation between stress and rubber content. It is not clear at this time whether rubber is a type of osmotic protectant against heat and water stress, but peak rubber content is correlated with the period when plants presumably experience high stress. This observation suggests that rubber and resin production is dynamic and can perhaps be regulated by environmental factors.

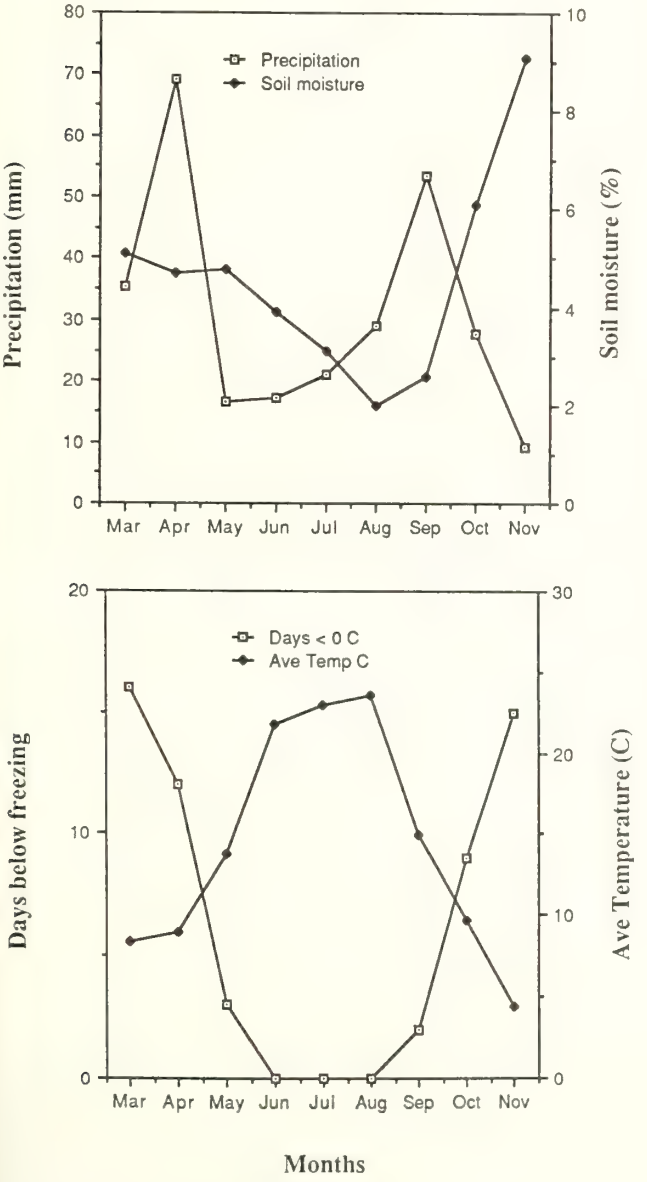

Figure 4--(upper) Precipitation (mm) and soil moisture (percent) and (lower) average temperature and days below freezing during the growing season at Goshen, Utah (Hegerhorst and others 1987b).

The change in the rubber and resin content in rabbitbrush could be explained in a number of ways. One possibility is that the resin production enzymes are more heat sensitive and are inactivated at higher temperatures. In contrast, the rubber production enzvmes may be more temperature stable and able to continue to function during periods of stress similar to the heat shock protein of soybeans (Key and others 1985). Another possible explanation for rubber and resin changes could be that the same basic pathway is functioning in both cases but the pathway has a junction point where the compounds are directed to resin production or rubber production. The partitioning of metabolites between the two pathways may be regulated by stress. Thus under periods of high stress the activity of the rubber pathway would be increased, whereas under periods of low stress the resin production would be favored. Further investigations are necessary to test these two hypotheses.

Another question which arises from these results is whether resin is broken down and converted to rubber and vice versa. The inversely correlated changes in the rubber and resin content would suggest that catabolic enzymes are functioning. This resin-rubber relationship would be an important aspect in storing harvested plants or in trying to stabilize rubber content before harvesting. Labeling experiments should be able to indicate whether breakdown and synthesis of the smaller compounds into rubber occur.

Changes in Other Secondary Metabolites

The contents of secondary metabolites in the resin extract were determined by GC-MS over the growing season. The total compounds in the cyclohexane fraction (fig. 5) followed the general resin

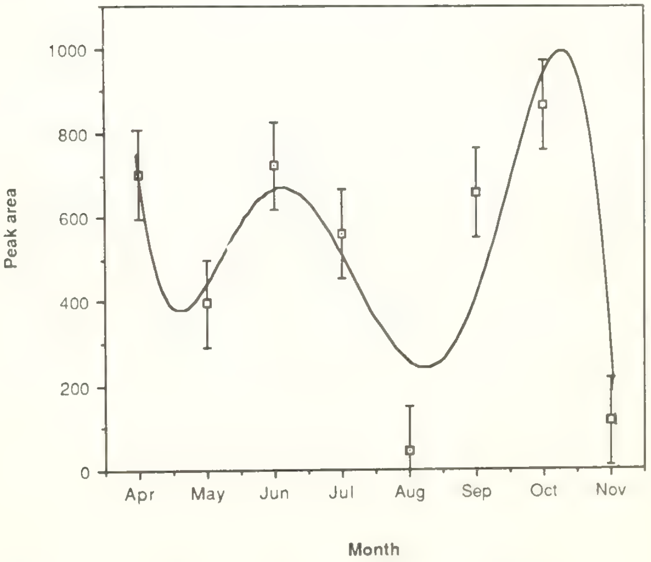

Figure 5--Total compounds in the cyclohexane fraction from Chrysothamnus nauseosus ssp. turbinatus during the growing season at Goshen, Utah. Vertical lines represent standard error bars (Hegerhorst and others 1987a).

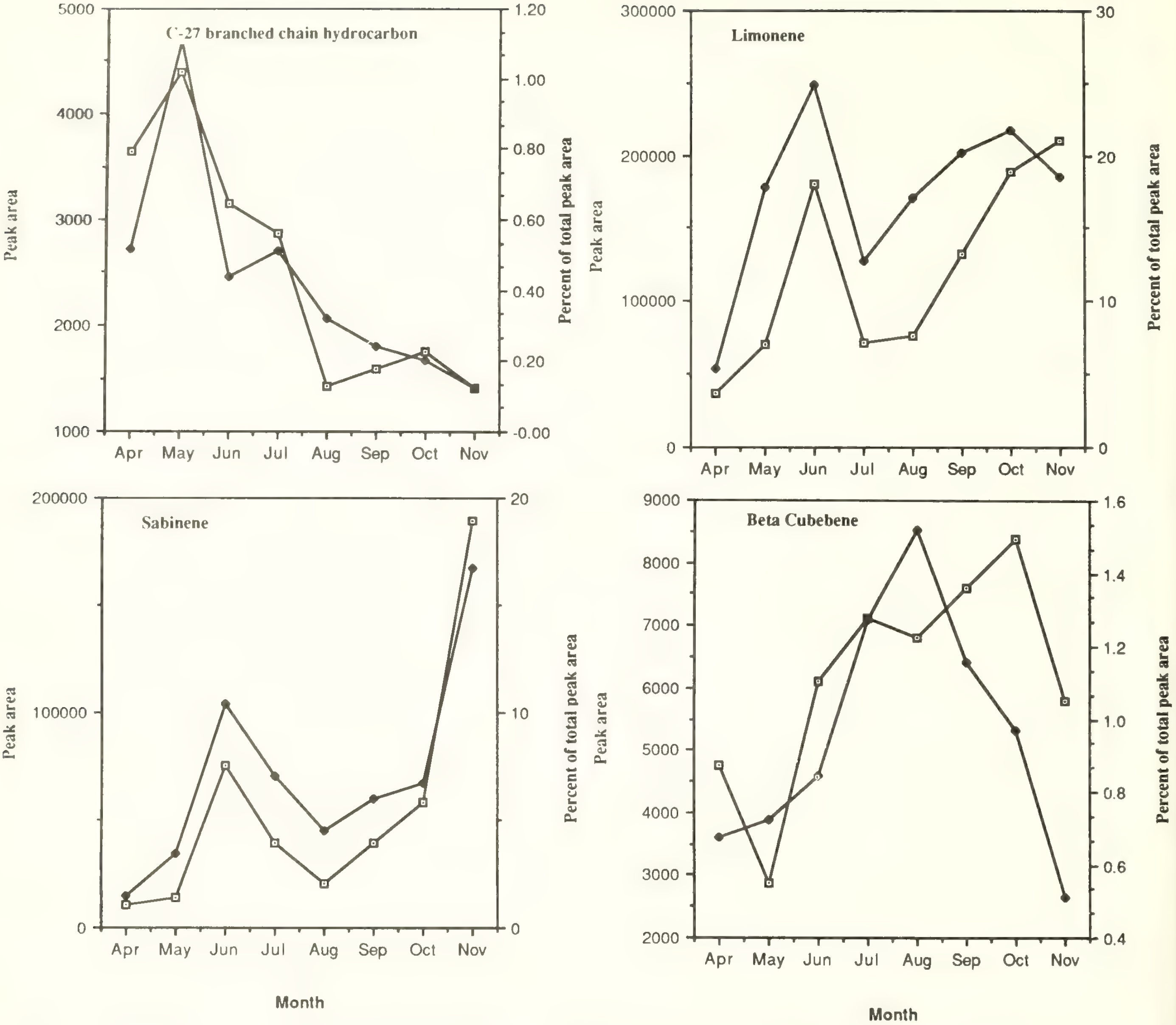

Figure 6--Changes in C-27 branched hydrocarbon (top left), Limonene (top right), Beta Cubebene (bottom right), and Sabinene (bottom right) from Chrysothamnus nauseosus ssp. turbinatus during the growing season at Goshen, Utah. The square represents the percent of the area of the compound in relation to the total area of all the compounds (Hegerhorst and others 1987c).

pattern but individual compounds varied within the growing season (Hegerhorst and others 1987a, 1987d). Simple and branched chain hydrocarbons increased in the early spring and then decreased throughout the remainder of the growing season (fig. 6). Limonene content was negatively correlated with rubber content but positively correlated with resin content (fig. 6). On the other hand Cubebene was positively correlated with rubber content and negatively correlated with resin content (fig. 6). A few compounds did not follow either pattern, such as Sabinene, which was low in the spring and increased during the growing season (fig. 6). Further studies are needed to elucidate the metabolite relationship between the changes in these compounds and changes in rubber and resin content.

DISTRIBUTION ALONG A STRESS GRADIENT

Samples of Chrysothamnus ssp. hololeucus were collected from the alluvial fan at the base of a steep slope and up the slope along a water stress gradient (Freeman and others 1987) in Kingston Canyon, south of Richfield, Utah. In addition to the water stress gradient established by Freeman and others (1987), we looked at several other soil factors that might influence plant physiological processes. Soils from the

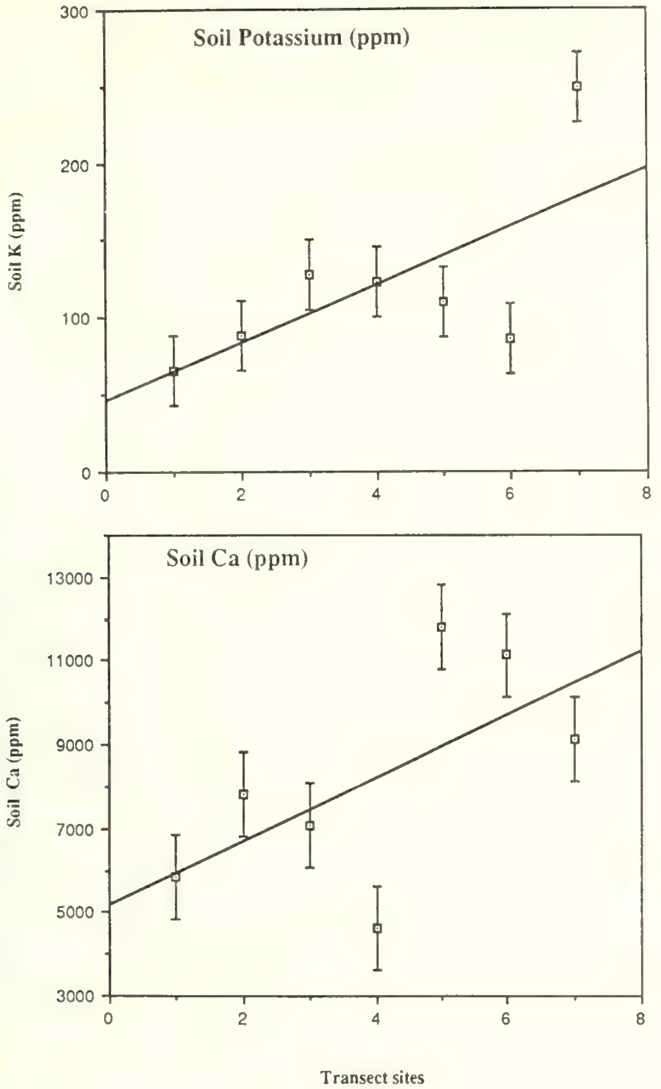

Figure 7--The potassium concentration (ppm) and the calcium concentration (ppm) in the soil from seven sites along a water stress gradient in Kingston Canyon south of Richfield, Utah. The lines were drawn by the method of least squares. Vertical lines represent standard error bars.

different collection sites on the alluvial fan and up the slope were collected and analyzed for percent silt, percent sand, percent clay, pH, P, NO$_3$, K, Ca, and Mg at the Brigham Young University soil laboratory using methods outlined by Hesse (1971). Potassium and Ca increased in concentration up the slope (fig. 7) whereas soil conductivity, soil nitrate, and soil organic matter concentration decreased up the slope (fig. 8). The soils texture, P, and Mg, varied little in relation to the slope. Three types of tissue (new growth, year-old growth, and several-years-old growth) were collected, ground, and the rubber and resin were extracted using the methods of

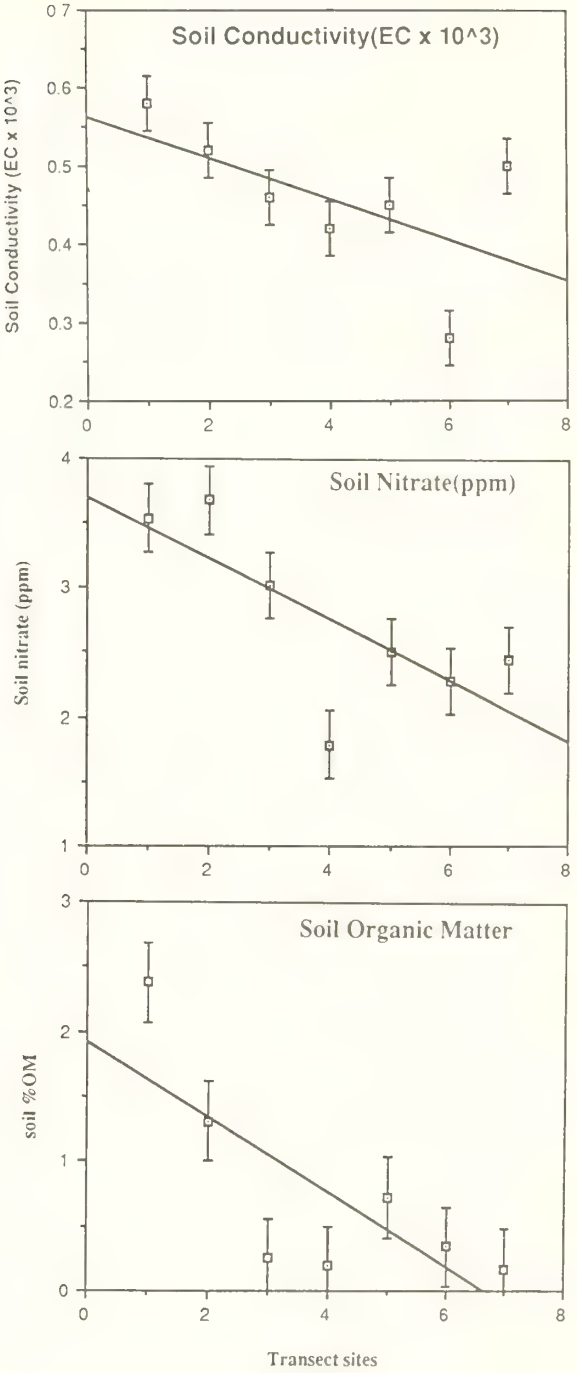

Figure 8--The conductivity (EC x 10^3), nitrate and organic matter in the soil from seven sites along a water stress gradient in Kingston Canyon south of Richfield, Utah. The lines were drawn by the method of least squares. Vertical lines represent standard error bars.

Table 1--Correlation table (r squared) for rubber and soil factors for three different age tissues of Chrysothamnus nauseosus ssp. hololeucus in relations to the stress gradient

Age of tissue	% OM	pH	EC x 10 3	Na	P	Nitrate	K	Ca	Mg	Clay	Silt	Sand
Rubber												
Green tissue	0.01	0.05	0.31	0.12	0.24	0.02	0.22	0.01	0.08	0.18	0.10	0.03
Year old tissue	0.24	0.04	0.03	0.22	0.02	0.44*	0.02	0.05	0.47*	0.01	0.01	0.03
Old tissue	0.03	0.16	0.01	0.18	0.26	0.14	0.24	0.21	0.36	0.20	0.03	0.13
Resin												
Green tissue	0.43*	0.05	0.55	0.05	0.11	0.26	0.02	0.45*	0.03	0.13	0.01	0.02
Year old tissue	0.18	0.17	0.21	0.11	0.36	0.02	0.07	0.03	0.22	0.03	0.01	0.01
Old tissue	0.14	0.16	0.19	0.14	0.55	0.004	0.02	0.18	0.14	0.03	0.18	0.12

*$p < .05$

Hegerhorst and others (1987c). The Ph of the soil at the different collection sites was 7.9 ± 0.03 (SE). Correlation analyses (r^2 values) of the different elements and properties of the soil with the rubber and resin content are listed in table 1 (Statview 512 1986). In the case of rubber in the year-old tissue, nitrate and Mg had a significant correlation ($p < 0.05$) (table 1). In the green tissues, significant correlation ($p < 0.05$) occurred between resin content and organic matter and Ca. However there were inconsistencies between the different tissues and the interpretation of the data is difficult.

RUBBER AND RESIN CONTENT AFTER TREATMENT WITH BIOREGULATORS, HIGH SALT, AND WATER STRESS

A controlled temperature chamber was used to grow transplanted seedlings of C. nauseosus ssp. consimilis. The 8-month-old plants (ten replicates) were treated with the following bioregulators: paclobutrazol (Pac) (2RS, 3RS)-1-(4-chlorophenyl) -4-4-dimethyl-2-1,4-triazol-yl-pentan-3-ol, XE-1019 [(E)-1-(4-chlorophenyl)-4-4-dimenthyl-2-1,-1-triazol-yl-penten-3-ol] Flurprimidol (Fl), [alpha-(1-methylethyl)-alpha-[4-(trifluoromethoxy) penyl]-5-pyrimidine-methanol], 2-(3,4-dichlorophenoxy)-triethylamine (DCPTA), to determine their effect on rubber and resin content. The bioregulators except DCPTA were applied as a soil drench at a dose of 150 μg per pot. DCPTA was applied as a spray (5,000 ppm) to the foliage. Also, plants (ten replicates) were treated with 0.5 M NaCl and with water deficiencies (50% normal water) to cause stress. Results (fig.9) indicated that there was a significant ($p < 0.05$) increase in resin content in plants or the initial plants. In the case of rubber (fig. 9), there was a significant ($p < 0.05$) decrease in the rubber content of the Pac-treated plants. Yokoyama and others (1986) reported an increase in rubber content in guayule plants treated with 2-(3,4-dichlorophenoxy)-triethylamine (DCPTA). Yokoyama and others (1986) used 100 ppm DCPTA on seeds and 2,000 ppm on 18-month-old guayule plants. We used 5,000 ppm of DCPTA and did not obtain a response in rubber rabbitbrush. Further studies using different dosages, application methods, and timing of

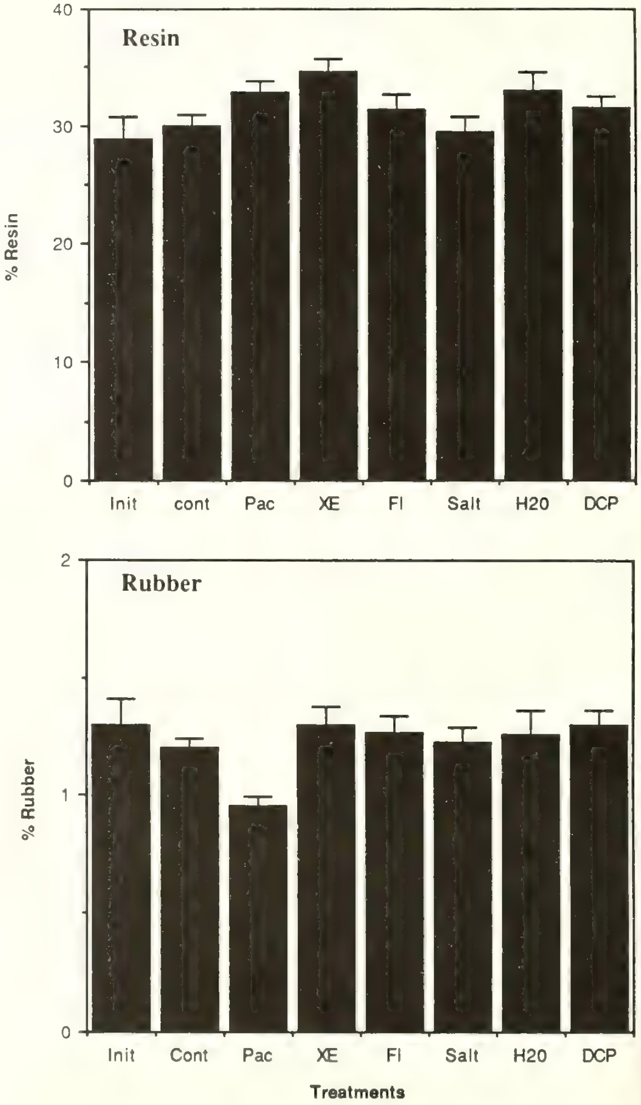

Figure 9--Resin content (upper) and rubber content (lower) of Chrysothamnus nauseosus ssp. turbinatus treated with different bioregulators and stress factors: Cont = untreated control; Pac = paclobutrazol (150 mg); XE = XE-1019 (150 mg); Fl = flurprimidol (150 mg); Salt = 0.5 M NaCl; H_2O = water stress treatments; DCP = DCPTA as a 5,000 ppm foliar spray.

bioregulator treatments are needed to fully assess the possibility of chemically regulating rubber content in rubber rabbitbrush. The rubber content did not increase under the level of water stress that we caused in our plants. Further studies at different levels of water stress are needed.

METABOLIC PATHWAYS OF RUBBER AND RESIN SYNTHESIS

The pathway of rubber synthesis has been associated with the mevalonic acid pathway. The pathway (fig. 10) involves branching around cis-isopentenyl pyrophosphate to either rubber or monoterpenoids (Robinson 1980).

Benedict and others (1986) found that the enzymatic synthesis of rubber in guayule was cold induced and that the enzymatic incorporation of isphentenyl pyrophosphate occurs on the surface of rubber particles. The rubber synthesis did not begin until the cool months of October and November. The enzymatic activity of cis-isopolyisopolymerase was related to the number of hours of 10°C and below. While the process of rubber synthesis in rubber rabbitbrush has not been studied as extensively as in guayule, it is obvious that regulator genes for the cis-isopolymerase in rubber rabbitbrush would have to function in response to heat or stress signals rather than cool temperatures. Although not clearly demonstrated, evidence suggests that the pathway from mevalonic acid to cis-isoprene is more closely tied with the formation of some terpenes than that of others. The significance of elucidating the exact relationship that exists between the resin and rubber formation is the potential of changing the flow of metabolites from monoterpenoids into natural rubber. If environmental signals such as high temperature, low moisture levels, and water stress could be imitated, it may be possible to favor the conversion from mevalonic acid to iso-pentenyl pyrophosphate and certain triterpenoids to natural rubber, rather than to monoterpenoids.

CONCLUSIONS

Rubber and resin contents of rubber rabbitbrush vary considerably depending upon tissue type, time of year, and growing conditions. Enhanced rubber production may be a stress response, which suggests the possibility of imposing stress treatments to increase rubber content. The possibility of using bioregulators to chemically alter rubber and resin contents of rubber rabbitbrush also exists. Whether any of these treatments would be commercially feasible remains to be determined.

ACKNOWLEDGMENTS

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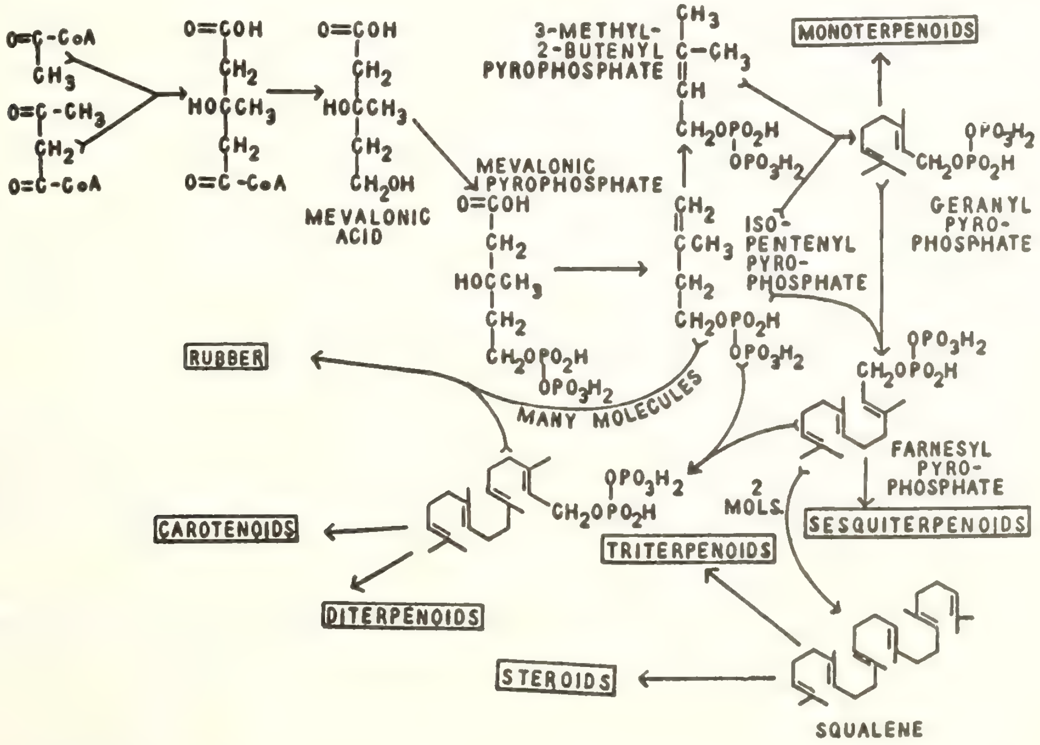

Figure 10--Simple diagram of pathways to resin and rubber compounds. Modified from Robinson 1980.

REFERENCES

Anderson, L. C. 1986. An overview of the genus Chrysothamnus (Asteraceae). In: McArthur, E. D., Welch, B. L., compilers. Proceedings--symposium on the Biology of Artemisia and Chrysothamnus. Gen. Tech. Rep. INT-200. 1984 July 9-13; Provo, UT. Ogden, UT: U.S. Dept. of Agriculture, Forest Service, Intermountain Research Station: 29-45.

Benedict, C. R.; Rosenfield, C. L.; Gale, M. A.; Foster, M. A. 1986. The biochemistry and physiology of isopentenylpyrophosphate incorporation into cis-polyisoprene is guayule plants. In: Benedict, C. R., ed. Biochemistry and regulation of cis-polyisoprene in plants. NSF Workshop. College Station, TX: Texas A&M University: 85-105.

Bolmann, F.; Dutta, L.; Robinson, H.; King, R. M. 1979a. New labdane derivatives from Chrysothamnus nauseosus. Phytochemistry. 18: 1889-1892.

Bolmann, F.; Zdero, C.; Robinson, H.; King, R. M. 1979b. New acetylene compounds from Chrysothamnus parryi. Phytochemistry. 18: 1519-1522.

Buchannon, R. A.; Cull, I. M.; Otey, F. H.; Russell, C. R. 1978. Hydrocarbon and rubber producing crops. Economic Botany. 32: 131-145.

Bucks, D. A.; Nakayama, F. S.; Allen, S. G. 1986. Regulation of guayule rubber content and biomass by water stress. In: Benedict, C. R., ed. Biochemistry and regulation of cis-polyisoprene in plants. NSF Workshop. College Station, TX: Texas A&M University: 161-173.

Davis, T. D.; Sankhla, N.; Anderson, W. R.; Weber, D. J.; Smith, B. N. 1985. High rates of photosynthesis in the desert shrub Chrysothamnus nauseosus ssp. albicaulis. Great Basin Naturalist. 45: 52-0526.

Davis, T. D. 1987. Diurnal and seasonal patterns of net photoshytnesis by irrigated Chrysothamnus nauseosus under field conditions. Photosynthesis Research. 11: 201-209.

Ehleringer, J.; Bjorkman, O. 1978. A comparison of photosynthetic characteristics of Encelia species possessing glabrous and pubescent leaves. Plant Physiology. 62: 185-190.

Ehleringer, J.; Mooney, H. A. 1978. Leaf hairs: effects on physiological activity and adaptive value to a desert shrub. Oecologia. 37: 183-200.

Foster, K. E.; Karpiscak, M. M.; Taylor, J. G.; Wright, N. G. 1983. Guayule, jojoba, buffalo gourd, and Russian thistle: Plant characteristics, products, and commercialization potential. Desert Plants. 5: 112-117, 126.

Freeman, D. C.; McArthur, E. D.; Sanderson, S. C.; Tiedemann, A. R. 1987. Environmental influence on sexual fitness components for three sexual morphs of Atriplex canescens. Unpublished manuscript, in review, and on file at Department of Biological Sciences, Wayne State University, Detroit, MI.

Hall, H. M.; Goodspeed, T. H. 1919. Rubber-plant survey of western North America. Univ. Calif. Publ. Botany. 7: 159-278.

Hegerhorst, D. F.; Bhat, R. B.; Weber, D. J.; McArthur, E. D. 1987a. Seasonal changes of selected secondary plant products in Chrysothamnus nauseosus ssp. turbinatus. Great Basin Naturalist. (submitted).

Hegerhorst, D. F.; Weber, D. J.; Bhat, R. B.; Davis, T. D.; Sanderson, S. C.; McArthur, E. D. 1987b. Seasonal changes in rubber and resin in Chrysothamnus nauseosus ssp. hololeucus and ssp. turbinatus. Biomass. (submitted).

Hegerhorst, D. F.; Weber, D. J.; McArthur, E. D. 1987c. Resin and rubber content in Chrysothamnus. Southwestern Naturalist. (in press).

Hegerhorst, D. F.; Weber, D. J.; McArthur, E. D.; Khan, A. J. 1987d. Chemical analysis and comparison of subspecies of Chrysothamnus nauseosus and related species. Biochemical Systematics and Ecology. 15: 201-208.

Hesse, P. R. 1971. Soil Chemical Analysis. London, England: John Murray Publisher. 520 p.

Key, J. L.; Kimpel, J. A.; Lin, C. Y.; Nagao, R. T.; Vierling, E.; Czarnecka, E.; Gurley, W. B.; Roberts, J. K.; Mansfield, M. A.; Edelman, L. 1985. The heat shock response in soybean. In: Key, J. L., Kosuge, T. eds. Cellular and molecular biology of plant stress. New York, NY: Alan Liss Publisher: 161-180.

McArthur, E. D. 1984. Natural diversity of western range shrubs. In: Cooley, J. L. and Cooley, J. H., eds. Natural diversity in forest ecosystems: Proceedings of the Workshop. 1982 November 29-December 1; Athens, GA. Institute of Ecology, Univ. of Georgia: 192-209.

McArthur, E. D.; Blauer, A. C.; Plummer, A. P.; Stevens, R. 1979. Characteristics and hybridization of important Intermountain shrubs. III. Sunflower Family. Res. Pap. INT-220. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

McKell, C. M.; Van Epps. G. 1980. Biomass energy production from large growing rangeland shrubs. Logan, UT: Institute for Land Rehabilitation, Utah State Univ. 78 p.

Maugh, T. H. 1982. Exploring plant resistance to insects. Science. 216: 722-723.

Ostler, W. K.; McKell, C. M.; White, S. 1986. Chrysothamnus nauseosus: a potential source of natural rubber. In: McArthur, E. D. and Welch, B. L., compilers. Proceedings; Biology of Artemisia and Chrysothamnus symposium. Gen. Tech. Rep. INT-200. 1982 July 9-13; Provo, UT. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 389-394.

Robinson, T. 1980. The organic constituents of higher plants. Their chemistry and interrelationships. North Amherst, MA: Cordus Press. 352 p.

Rose, A. F.; Butt, B. A.; Jermy, T. 1980. Polyacetylenes from the rabbitbrush C. nauseosus. Phytochemistry. 19: 563-566.

Smith, B. N. 1987 [Personal communication]. September 14. Provo, UT: Brigham Young University.

Statview 512. 1986. Statistic software. Brainpower. Calabass, CA. 35 p.

Stevens, D. J.; Brough, R. C.; Griffin, R. D.; and Richardson, E. A. 1983. Utah weather guide. Brigham Young University Printing Service, Provo, UT. 46 p.

Weber, D. J.; Davis, T. D.; McArthur, E. D.; Sankhla, N. 1985. Chrysothamnus nauseosus (rubber rabbitbrush): multiple-use shrub of the desert. Desert Plants. 7: 172-180, 208-210.

Yokoyama, H; Hsu, W. J.; Hayman, E. 1986. Bioregulation of rubber synthesis in guayule. In: Benedict, C. R. (ed.). Biochemistry and regulation of cis-polyisoprene in plants. NSF Workshop. College Station, TX: Texas A&M University: 129-138.

U.S. GOVERNMENT PRINTING OFFICE: 1989-0-673-039/81008

Wallace, Arthur; McArthur, E. Durant; Haferkamp, Marshall R., compilers. 1989. Proceedings--symposium on shrub ecophysiology and biotechnology; 1987 June 30-July 2; Logan UT. Gen. Tech. Rep. INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 183 p.

Fifth in a series of proceedings of symposia on wildland shrubs. Has sections on biotechnology and breeding, environmental management and technology, and ecophysiology of western shrubs. Twenty-four papers are included.

KEYWORDS: wildland shrubs, breeding systems, vegetation establishment, water relations, stress responses, plant nutrition

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Compilers:

DENNIS E. FERGUSON, Research Forester, Intermountain Research Station

PENELOPE MORGAN, Coordinator of Continuing Education and Outreach and Assistant Professor, College of Forestry, Wildlife and Range Sciences, University of Idaho

FREDERIC D. JOHNSON, Professor of Forest Ecology, College of Forestry, Wildlife and Range Sciences, University of Idaho

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FOREWORD

Directly after Kent Houston and Ken Neiman suggested this symposium, people began asking "Why have we waited so long?" The committee members, program reviewers, speakers, and others were all enthusiastic and willing to participate. Now was a good time for a symposium on land classifications based on vegetation. Many classifications of climax plant associations for the western United States and western Canada are completed. It was time to summarize that progress and ask the question "Where do we go from here?"

The committee endeavored to invite speakers from different locations and disciplines that use land classifications based on vegetation. Topics were chosen to bring out theoretical concepts as well as practical applications of these classifications. Still, we knew that not all potential speakers could be squeezed into a 3-day session. The poster session provided a forum for additional authors, applications, demonstrations, and newly completed studies.

Sponsors of the symposium were the University of Idaho, College of Forestry, Wildlife and Range Sciences; University of Idaho, College of Agriculture; and USDA Forest Service, Intermountain Research Station. Sponsors contributed time, resources, and funding to support this effort. Other organizations which cooperated with us include the University of Montana, School of Forestry; Montana Cooperative Extension, Office of Extension Forestry; Washington State University, Department of Forestry and Range Management and Cooperative Extension; Society of American Foresters; Society for Range Management; and The Wildlife Society, Northwest Section. We thank each of these organizations for their help. Donna Germer and Janet Yoder, University of Idaho Conferences and Enrichment Program, handled registration, fees, meeting room arrangements, and the like, and were indispensable to the success of the symposium.

A special thanks goes to Rexford Daubenmire for being our keynote speaker. At the symposium banquet, it was gratifying to learn that the Clearwater National Forest is setting aside a botanical area on Walde Mountain for study of a species discovered by Rexford Daubenmire, Dasynotus daubenmirei. Also at the banquet, David Alt, Professor of Geology at the University of Montana, gave a spectacular speech on Glacial Lake Missoula and the Spokane Floods.

Last, we thank the symposium speakers and poster presenters. Their enthusiasm and dedication are much appreciated. Authors prepared their camera-ready papers, obtained peer review, and are responsible for content. We believe they did an excellent job and hope you agree.

Frederic D. Johnson and Dennis E. Ferguson,
co-chair
Penelope Morgan,
Continuing Education and Outreach

Raymond J. Boyd	James M. Peek
Maynard A. Fosberg	Robert D. Pfister
Minoru Hironaka	Edwin W. Tisdale
Kent Houston	Charles A. Wellner
Kenneth E. Neiman	

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WELCOME

Leon F. Neuenschwander

Associate Dean
College of Forestry, Wildlife, and
Range Sciences
University of Idaho

Welcome to the University of Idaho and to this symposium: Land Classifications Based on Vegetation, Applications for Resource Management. It is my privilege to welcome you to the University of Idaho which is a cosponsor of this symposium with the Intermountain Research Station, USDA Forest Service. The proceedings from this symposium will be published by the Intermountain Research Station.

The keynote speaker is Dr. Rexford Daubenmire who began this effort here in the Pacific Northwest. The 43 papers presented at this symposium represent an impressive collection of experience, expertise, and diversity. They will not only provide historical and evolutionary aspects of classification systems. The speakers will undoubtedly ask questions that future research will need to answer as classification evolves into the next century.

WELCOME

Laurence E. Lassen

You may have noticed the symposium title is in two parts--"Land Classifications Based on Vegetation" and "Applications for Resource Management." The symposium committee has recognized that there are two important items to discuss these next 3 days--development of classification systems and the transfer of information to land managers.

The Intermountain Research Station (INT) has been involved in Land Classifications Based on Vegetation for a long time. Nearly six decades ago, J. A. Larsen (1930) published a paper on climax types in the northern Rocky Mountains. The determination of climax types was thought to be controlled by topography and climate. He identified six climax types for the northern Rocky Mountains and even included a table listing species' shade tolerance, a list nearly identical to those in use today.

Of course, Rexford Daubenmire is the person who developed a classification system for the northern Rocky Mountains, a system described in his 1952 monograph and a 1968 paper co-authored with Jean Daubenmire, who is also attending the symposium. We are delighted the Daubenmire's are able to be here. Portions of the symposium will deal with habitat types, and we hope you will be pleased to see the growth in use of this classification system--something to which you devoted a considerable part of your careers.

Assistant INT Station Director, Chuck Wellner, now retired, is another person who championed the cause of land classification systems based on vegetation. In 1966, Chuck went to Rexford Daubenmire to discuss classification of forests in the Intermountain area. Graduate students of Daubenmire completed two classification projects in Wyoming under cooperative agreements as a direct result of that meeting.

Research and Development cooperative agreements were initiated with the Northern Region, and then the Intermountain Region, of the Forest Service. INT provided leadership under the direction of Bob Pfister, and the Forest Service Regions funded a good deal of the project and provided field crews. A large project got under way in 1971 in Montana's forests. Within a year, range and shrubland was being classified under the direction of Walt Mueggler. About 2 years later, Bob Steele, under Pfister's direction, was spearheading an effort in central Idaho. INT scientists continue this effort and have published many general technical reports describing land classification systems in the Intermountain West.

Equally important is the second part of the title, "Applications for Resource Management." A researcher's job is incomplete until ideas and techniques are put into practice. Part of that job is accomplished through publications. The proceedings of this symposium will be recorded in an INT General Technical Report. A continuing part of the job will be through participation in future workshops and in individual and small-group consultations with resource managers.

Of course, another way INT helps get research results applied is in helping to sponsor symposia like this one. This symposium is a forum for us to exchange ideas and share experiences. You will learn what has been done in the field of land classifications based on vegetation, how the systems are used, what problems had to be overcome, how we could be doing some jobs better, and what remains to be done.

Stay tuned for an exciting program.

REFERENCE

Larsen, J. A. 1930. Forest types of the northern Rocky Mountains and their climate controls. Ecology. 11: 631-672.

Laurence E. Lassen is Director, Intermountain Research Station, Forest Service, USDA, Ogden, UT.

THE ROOTS OF A CONCEPT

Rexford Daubenmire

ABSTRACT: Some experiences which led to the development of the Habitat Type concept are described. Also the publications of some early workers who championed principles included in the Habitat Type are briefly reviewed.

INTRODUCTION

When I was invited to give some introductory remarks to this symposium, I welcomed the opportunity to participate in discussions of a subject which was, for a long time, a major focus of my research interest. But later, on seeing the list of assigned subjects, I had second thoughts, realizing that it might be difficult to say anything without impinging on the turf of other symposium speakers. This problem seemed solved, however, when it was suggested that I simply outline briefly the origin and development of the Habitat Type (HT) concept.

Most of my schooling was east of the Mississippi River, and during graduate training at the University of Minnesota I took a course in Plant Geography. There the classic publications of C. H. Merriam on southern Idaho and Arizona were given considerable emphasis. So in 1936, when I was appointed Assistant Professor in the Department of Botany at the University of Idaho, I expected the mountain vegetation here to be somewhat similar to the schematic diagram of Merriam's (1890) system (fig. 1) that was well known at that time. But my first trip into the foothills of the forested mountain which rises from the prairie just a few miles north of this city proved quite disconcerting. I had scarcely left the dry prairie and entered the forest when I saw Engelmann spruce growing along creek margins. Then farther into the mountain, ponderosa pine was seen extending up ridge summits to near the top, approximately 3,000 ft (600 m) higher. Obviously a lot of work would be needed if I was ever to gain an understanding of this unexpected reversal of Merriam's altitudinal relationships.

INFERENCES FROM INVENTORIES

During my doctorate research in Minnesota I had developed a keen appreciation for the significant inferences that can be drawn from a table that represents a complete inventory of the trees in a sizable portion of a homogeneous forest stand. The distribution of the size classes for each species, serving as a crude indicator of relative age within that species, tells much of the past history of that stand, as well as suggesting its future status. So on my first field trip with students into the nearby mountains, I had the class lay out a large plot in an old clearcut, then asked them to divide up and assemble an inventory of all the trees, keeping separate the size-class data for each species. Table 1 is a summary of the data.

To judge from the relatively large individuals, most of the species obviously had considerable seedling success early in the regeneration cycle. Some of them probably invaded quickly, but the seedlings of these species had stopped surviving years ago. It could be predicted that, barring another disturbance, these trees would eventually lose representation on the site.

Seedlings of one of the species, however, had for some time continued to be quite successful despite the closing of the canopy, so it might eventually be left as the sole dominant of the overstory. The absence of western redcedar in the largest size classes could signify either a lateness of its invasion, or perhaps just a slower rate of growth in individuals that had actually arrived as early as those species represented by large trees. A hypothesis that old western redcedar trees could alone form the tree canopy was later proven by finding a number of stands scattered from Montana to British Columbia to Washington, one even on the same mountain that the class had sampled.

By continuing to emphasize seedling success rather than the composition of the current tree dominants, the south slope of the same mountain was found to provide environments suitable to support only four potential tree dominants (Daubenmire 1980). These four types of environment later proved to represent segments of a soil-moisture continuum ranging from one especially conspicuous on ridge crests where a short dry period developed late in summer, to the fourth that is best developed on the lower slopes of ravines where the soil profile remains moist the year around. The spruce and ponderosa pine distributions, which puzzled me at first, now had a rational explanation.

Paper presented at the Symposium "Land Classifications Based on Vegetation: Applications for Resource Management," Moscow, ID, November 17-19, 1987.

Rexford Daubenmire is Professor Emeritus of Botany, Washington State University, Pullman, WA; currently living in Sorrento, FL.

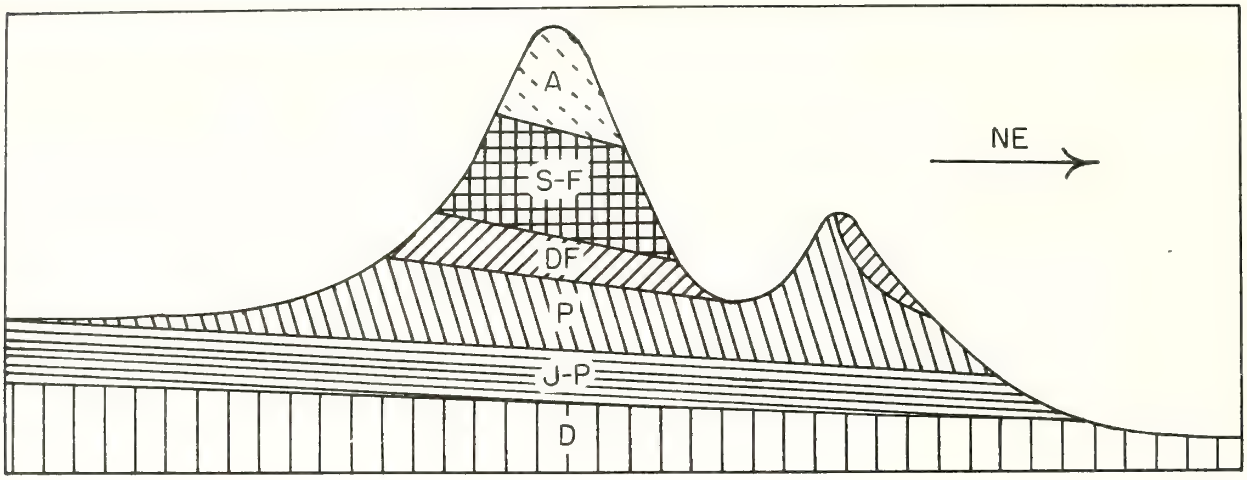

Figure 1--Diagram of vegetation as related to topography in northern Arizona, after Merriam (1890). A = Alpine, S-F = Spruce-fir, DF = Douglas-fir, P = Ponderosa pine, J-P = Juniper-pinon, D = Desert.

Later, as the data for a number of western redcedar stands accumulated, it became clear that essentially pure stands of this tree occur in very contrasted environments. On well-drained sites the tree has a sparse undergrowth of low shrubs and herbs. But the same tree may dominate swamps where the undergrowth includes a complete cover of the thorny Devil's club. This phenomenon, with one type of climax tree cover embracing different kinds of environment as shown by differences in the undergrowth, proved to be common. Then the reverse phenomenon was also found repeatedly, that is, with the same undergrowth type occurring beneath different climax trees (Daubenmire and Daubenmire 1968). Overstory types (table 2) here aligned across the top, simply reflect segments of a continuum from warm-dry at the left, to cold-wet on the right. The principal dominants of the undergrowth types to be found in each of the moisture-temperature ranges as indicated by trees are listed down the left side. Climax undergrowth types obviously respond differently to the complex environmental mosaic--in places their limits correspond with limits critical for the trees, but elsewhere they show remarkable insensitivity to tree limits. Soils and microclimates seem relatively more important for the ground vegetation, and so it adds a second dimension to an ecologically based vegetation classification. Each distinctive combination of overstory plus undergrowth, defines the extent of environment that has a high degree of homogeneity among all the land areas supporting that combination. In other words, the potential vegetation defines distinctive Habitat Types (HTs).

Since overstory types reflect moisture-temperature relations almost alone, they facilitate correlation among different parts of the Rockies, which would be rather difficult using undergrowth for the first level of correlation.

EARLIER CLASSIFICATIONS

Now I would like to relate the HT to some earlier forest classifications that had been developed elsewhere.

Table 1--Tree density/750m², Crumarine Creek, Latah County

	Diameter (at breast height) classes						
	0-1 dm			1-2	2-3	3-4	4-5
	Under 0.5 dm						
Species	Under 1 m tall	Over 1 m tall	Over 0.5 dm				
Western redcedar	[1]20	53	42	30	2		1
Grand fir		7	28	38	10	1	
Western larch			6	13	5	1	
Mountain maple			1	[2]7			
Western white pine				5	10	4	1
Paper birch				2			
Engelmann spruce				1	1		
Douglas-fir					3	3	1

[1] All representing layered branches.

[2] All from one stump; represent maximum size for species.

Table 2--Undergrowth communities found in association with climax trees of overstory in northern Idaho-eastern Washington

Dominant plants of undergrowth types	Overstory dominants						
	Ponderosa pine	Douglas -fir	Grand fir	Western redcedar	Western hemlock	Subalpine fir	Mountain hemlock
Needle-and-thread	+						
Idaho fescue	+						
Bitterbrush	+						
Rose and Snowberry	+	+					
Ninebark	+	+					
Pinegrass		+					
Lady fern				+			
Devil's club				+			
Mountain box			+	+	+	+	
Grouseberry						+	
Beargrass						+	+
Fool's huckleberry						+	+

Vegetation classification is indeed a very old concept. It probably got started as soon as hominoids developed language which enabled them to convey abstract thoughts to one another. This is suggested by the fact that most primitive tribes today have a vegetation classification for their own territories. They distinguish ecosystem types by their vegetation, and have learned what useful products may be obtained from each.

As Caucasian civilization developed, vegetation classification as a cultural attribute tended to atrophy, for with the exception of a continuing dependence on wood for fuel, most basic needs came to be furnished by crops and livestock. Eventually, increasing demands for wood for the construction of buildings and ships as well as for fuel led to sufficient forest depletion that tree planting became necessary. It was obvious that each tree species does not grow equally well in all vegetation types where it occurs or may be planted, and vegetation classification appeared to have potential value.

At the beginning of our century, the Russian forester G. F. Morosov was teaching and publishing work emphasizing the indicator significance of vegetation. Written in the Russian language, his publications seem to have gained little more than local attention.

In 1926 the Finnish forester A. K. Cajander, apparently inspired by Morosov's work, presented a classification of Finland's forest communities. His study, originally written in the Finnish language, was unique in that it ignored species composition in the tree stratum. It was based entirely on just the undergrowth shrubs, herbs, and cryptogams. Such a perspective may have some justification in that Finland is small, is completely blanketed with glacial drift, and is topographically rather uniform. His classification gained considerable interest, especially after translation, for he demonstrated its value in forest management.

Two years after Cajander's classic publication appeared, one of Morosov's students, V. N. Sukatchev (1928), presented a classification for the extensive belt of spruce forest across northern Russia. The name of each of his forest types combined the genus of the forest tree with the name of the most diagnostic plant in the undergrowth. Although this appears to have been the first time more than one vegetation stratum was used in naming a forest community, the system otherwise was not basically different from that of Cajander. Since he did not distinguish between the western spruce forests of *Picea abies* and the eastern spruce forest of *P. obovata*, this was just a classification of undergrowth. Although a Russian, Sukatchev published in a prestigious British journal, yet his use of binomials in referring to different combinations of vegetation strata gained no support from subsequent forest classifiers.

On our side of the Atlantic, F. E. Clements and H. C. Cowles were at the same time vigorously pushing a viewpoint that succession should be the center of interest in plant ecology. Europeans had treated their forest types as being essentially static, or climax. In the American view all but one of the extremely diverse communities in a large area are essentially seral stages that lead to the same climax type. Clements' and Cowles' ways of explaining what motivated such great transformations differed, but both were committed to this, the monoclimax hypothesis. Both men were good salesmen and through their advocacy of it, the hypothesis gained wide acceptance in North America. But in Europe, succession continued to get negligible attention until eventually it was given a new perspective by A. G. Tansley's (1935) contention that there may be several equally stable kinds of communities in a given landscape mosaic, if that landscape includes several distinctive kinds of environment. This is the polyclimax concept, which finds favor with perhaps most ecologists today.

Although a number of continental Europeans have proposed still different approaches for vegetation classification, a combination of national pride and personal ego prevented objective testing of their relative merits. Indeed, there was so much discord among vegetation investigators at science conventions early in this century that classification became generally discredited as a field deserving development in community ecology. Nevertheless, a few of the older proposals still have a following. Cajander's approach has been advocated in Montreal and in New York State, and Braun-Blanquet's method has gained acceptance in many places outside its home grounds in the Alps.

HT CONCEPT SURVIVAL

I suspect that had I not documented the value of HTs for predicting tree growth and mistletoe susceptibility (Daubenmire 1961), with a forester then testing the approach independently and finding it useful (Roe 1967), the HT concept too might have passed into virtual oblivion.

But the HT approach has met with some rebuffs. For example, the Soil Conservation Service once asked me to give a series of lectures on synecology to a group of field personnel which the Service brought together each year in Lincoln, Nebraska. The person organizing this session, knowing of my interest in HTs, discretely suggested that I devote minimal time to this subject, because, he said, it applied to only the region in which it was developed! Apparently he did not think an ecological principle was involved, and apparently he did not like my interpretation of the word "minimal," for I was not asked back next year. Despite his opinion, the concept has been used widely in the Rocky Mountains, in deciduous forests in Michigan and Ohio, and in steppe vegetation. It seems to be a fundamental perspective that is useful wherever natural vegetation is still reasonably intact.

REFERENCES

Cajander, A. K. 1926. The theory of forest types. Acta Forest. Fenn. 29: 1-108.

Daubenmire, R. 1961. Vegetative indicators of rate of height growth in ponderosa pine. Forest Science. 7: 24-34.

Daubenmire, R. 1980. Mountain topography and vegetation patterns. Northwest Science. 54: 146-152.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agricultural Experiment Station. 104 p.

Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountain region and the desert of the Little Colorado, Arizona. U.S. Department of Agriculture, North American Fauna 3: 1-136.

Roe, A. L. 1967. Productivity indicators in western larch forests. Res. Note INT-59. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Sukatchev, V. N. 1928. Principles of classification of the spruce communities of European Russia. Journal of Ecology. 16: 1-18.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology. 16: 284-307

CLASSIFICATION OF HABITAT TYPES IN THE WESTERN UNITED STATES

Charles A. Wellner

ABSTRACT: Progress in developing land classification by vegetation habitat types in the western United States from the time Daubenmire published his concept of habitat types to the present is described by three periods: through 1970, 1971 through 1980, and 1981 through 1987. In the initial period, ecologists and land managers became familiar with the concept, tested it, and developed classifications for limited areas. During the 1971 through 1980 period, progress in developing habitat type classifications increased dramatically. The number of published classifications was even greater during the 1981 through 1987 period because of work begun in the previous period and new classification programs. The USDA Forest Service has accounted for most of the progress through in-service classification programs and cooperative agreements with university scientists. Because foresters badly needed an ecologically based land classification, they readily accepted the habitat type system. As a result, classifications have been developed for most of the forest land in the western United States. Classification by habitat type of non-forest land is progressing more slowly. The development of classifications by habitat types is far from complete in the western United States. Classifications need to be developed for forest lands not yet classified, and the non-forest lands especially need attention. Existing classifications need to be better correlated. Seral communities within many habitat types need to be classified, their successional pathways determined, and the management implications assessed. Finally, habitat types need to be better fitted into an overall land classification framework.

INTRODUCTION

During the last 20 years, we have witnessed great interest and progress in developing classification systems that relate or integrate knowledge needed for land management (Bailey 1982; Brown and others 1980; Driscoll and others 1984; Pfister and others 1973; Wertz and Arnold 1972). This has come about through increasing knowledge of processes and functioning of plants, animals, and ecosystems; greater management experience; and increasing interest in public lands and their management; all sharpened by a number of Congressional acts that mandate ecological management of Federal forest and range lands. Attempts to relate and integrate knowledge of climate, landforms, soils, and vegetation both existing and potential--all needed in land management--are ongoing.

I will confine this paper to the remarkable extension through the western United States of Rexford Daubenmire's concept of land classification by vegetation habitat types. A number of ecologists, including Pfister (1977, 1982), Pfister and Arno (1980), and Franklin (1980) have previously reviewed progress in ecological classification of forest vegetation. This account will attempt to bring the extension of classification by habitat types up to date. I acknowledge the help of papers of the foregoing ecologists, and a number of people, especially the Regional Forest Service ecologists--Wendel Hann, Barry Johnston, Will Moir, Al Winward, David Diaz, and Fred Hall--and several Idaho ecologists, especially Ed Tisdale, Min Hironaka, and Bob Steele. And my apologies for omissions and errors that occur in my account.

Following are some sideboards to this review. Theory and methodology of habitat type classification are not discussed, mainly because these topics have been described by a number of scientists, especially Daubenmire (1952), Daubenmire and Daubenmire (1968), Franklin and others (1970), Hall (1980), Moir and Ludwig (1983), Pfister and Arno (1980), Schlatterer (1983), Stewart and Hann (1983), and Pfister (this proceedings). Classifications by range sites and classification of riparian vegetation are not included. However, classfications using terminology other than habitat types, such as plant associations that are based on potential climax vegetation to classify land areas capable of producing similar plant communities at climax, are included. Also included are classifications of seral vegetation into community types that explain succession within habitat types and the management implications involved.

BEFORE DAUBENMIRE

Let us start with the forest classification situation in the northern Rocky Mountains before Daubenmire. From an ecological standpoint, it was simply chaos. We used broad forest cover types to classify forests. The Society of American Foresters cover types was one classification in use. The Forest Service used a similar but slightly different classification of existing forests for forest inventory and timber sales purposes. These classifications in some instances

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Charles A. Wellner, formerly Assistant Director, Intermountain Research Station, now retired, Moscow, ID.

accommodated economic values. For example, the western white pine type was defined as any stand that contained 15 percent or more western white pine and the ponderosa pine type included any stand that contained 25 percent or more ponderosa pine. Western larch and Douglas-fir were often classified together as Larch-Fir because wood properties and values of the two species were similar and they sold in the same market. Classification of forests was largely for the purpose of forest regulation, timber sales, and to determine the timber supply situation. Classification served the purposes intended but was not geared to ecological management of forest lands. This did not mean that foresters lacked understanding of the successional role of forest species. Tolerance of tree species and their role in succession were known early in the century and were described in numerous publications, but this knowledge did not enter to any great extent in classification.

The lack of classification based on the ecology of the forest land led to serious problems for forest research scientists and forest managers. For example, the silvicultural research program in the Intermountain Research Station was organized by broad forest types. Although the site conditions under which research was conducted were described in publications, results often were considered by managers to apply broadly. When land managers tried to apply research results, at times they found them unsatisfactory for their conditions. As a result, the research was questioned. This happened often enough that both research scientists and forest managers realized an ecologically based classification system was needed. The need became especially critical after World War II when intensive management of National Forests increased markedly, and we were able to expand our research programs to most major ecosystems.

In the northeastern United States, Westveld (1951) had expressed the need for an ecological classification as a guide to better silviculture. He proposed a classification for spruce-fir and northern hardwood forests based on climax tree species and indicator understory species to arrive at site-types. In essence, Westveld proposed a classification that Daubenmire a year later termed habitat types. However, Westveld's proposal apparently did not gain acceptance.

1952 THROUGH 1970

When Daubenmire (1952) published his paper on forest habitat types, many foresters in northern Idaho were interested. We began trying the classification in northern Idaho forests. The 1950's were a period of becoming familiar with the classification, testing it, and determining our ability to use it. By the early 1960's, a number of us were convinced that classification by habitat types was a system that would meet research and management needs. Research silviculturists in Moscow, ID, and Missoula, MT, began using habitat types to help describe the ecological situation of their studies and in reporting results and recommending practices. However, the problem facing us was that we had a classification only for northern Idaho and northeastern Washington. We tried to extrapolate the classification to the east and south, but this was not satisfactory. The need was to extend the classification to all forest and range lands in the Intermountain West. I talked with Blair Hutchinson and Jack Wikstrom, both responsible for Forest Survey in Rocky Mountain States, about including habitat types in an upcoming resurvey of forest lands in northern Idaho, explaining the benefit of habitat types in the management of all resources. They were enthusiastic. So was Sam Evans, the Northern Region Silviculturist. When the resurvey was completed, Glenn Deitschman, Project Leader of the Intermountain Station's silvicultural research project in Moscow, checked survey plots to determine the accuracy of habitat type determinations. When he reported that only 50 percent were classified correctly, we were dismayed! These discouraging results pointed up the need for intensive training in habitat type classification not only for inventory crews but for all those engaged in forest management. This emphasized the need for intensive training in the habitat type concept by university and Forest Service ecologists and the inclusion of habitat type classification in university courses.

A major problem still remained: we had a classification developed for only a limited area--how to finance and staff an extension of the classification remained. I visited Dr. Daubenmire on February 2, 1966, to discuss the problem with him. He suggested that we fund graduate students, each of whom would develop a classification for vegetation in a specified area as a dissertation subject. We were able to get funds from the Washington Office to help do this and decided to leapfrog the effort to western Wyoming. The result was Reed's (1969) thesis on vegetation of the Wind River Mountains. Later a similar arrangement was used to fund Cooper's (1975) graduate work in northwestern Wyoming.

In the mid-1960s, the Intermountain Region of the Forest Service was having problems obtaining adequate regeneration of Engelmann spruce. The Regional Forester, Floyd Iverson, halted spruce sales until we determined how to regenerate the high-elevation spruce forests. We assigned Arthur Roe, Project Leader of a silvicultural research project in Missoula, to determine whether and wher research was needed. He and Allan Dahlgreen, in charge of regeneration and planting in the Intermountain Region, examined problem areas and determined that existing knowledge, if followed, would take care of regeneration problems over much of th spruce type, except in southern Utah. Bob Pfister who had taken Roe's place as Project Leader of silvicultural research, was assigned to the resear job in southern Utah. His work pointed to the nee for the classification of spruce sites on an ecological basis. As a result, he developed a habitat type classification of high-elevation forests of Utah as his Ph.D. dissertation working under Dr. Daubenmire. We were modestly on our way in developing a habitat type classification for forests of Utah.

Table 1 shows habitat type classifications through 1970 in western United States and location of classification efforts is shown in figure 1.

Table 1--Classifications of habitat types completed or in progress by 1970 in the western United States, listed chronologically by Forest Service region. The general location of listed studies is shown in figure 1. See references for complete citation

Forest Service region	References
Northern (Montana, northern Idaho, North Dakota, & northwestern South Dakota)	Daubenmire 1952 Mueggler 1965 Daubenmire and Daubenmire 1968 Daubenmire 1970
Rocky Mountain (Colorado, Kansas, Nebraska, South Dakota, and eastern Wyoming)	Steen and Dix 1970[1]
Intermountain (Nevada, Utah, western Wyoming, and southern Idaho)	Reed 1969 Pfister 1972[1]
Pacific Northwest (Oregon and Washington)	Driscoll 1964 Corliss and Dyrness 1965 Bailey 1966 Dyrness and Youngberg 1966 Franklin 1966 Hall 1967

[1] Initiated, but not completed.

Daubenmire and Daubenmire (1968) had completed a classification of forest sites in northern Idaho and northeastern Washington, and Daubenmire (1970) had developed a classification of steppe vegetation of eastern Washington. Mueggler (1965) had studied succession in certain western redcedar and western hemlock habitat types in northern Idaho. Reed (1969) had completed his Ph.D. dissertation on forest vegetation of the Wind River Range in Wyoming. Pfister (1972) had completed field work on his classification of high-elevation forests of Utah but had not yet completed his dissertation. Steen and Dix (1970) were working on classification of subalpine forests of Colorado.

In the Pacific Northwest Region of the Forest Service, Driscoll (1964) had developed vegetation-soil units in the central Oregon juniper zone, and Franklin (1966) had completed his dissertation on subalpine forests of the southern Washington Cascade Range. Students, mainly of C. E. Poulton at Oregon State University, who was a 1953 graduate student of Daubenmire's, were developing habitat type classifications for limited areas in Oregon: Corliss and Dyrness (1965) on the coast, Bailey (1966) in the southern coastal area, and Dyrness and Youngberg (1966) for ponderosa pine forests of central Oregon. Hall (1967) completed a dissertation working under Poulton on vegetation-soil relations as a basis for resource management in the Ochoco National Forest. Hall modified the habitat type concept to include not only potential but also seral vegetation, soils, landforms, and management implications.

The period 1952 through 1970 was highlighted by further development of the concept of classification by habitat types by Daubenmire, scientists and land managers becoming familiar with the concept and testing it at various locations, and especially the training of young scientists in the concept, mainly as graduate students of Daubenmire and Poulton, but some elsewhere. Such a cadre of trained ecologists was crucial to extend the concept. Also, the need to train scientists and land managers was recognized, and training programs were begun. Extension of the habitat type concept was on its way by 1970, but classifications had been developed for only a limited area of land.

1971 THROUGH 1980

Table 2 lists completed classifications by Forest Service regions during this period. Figure 2 shows where they occurred.

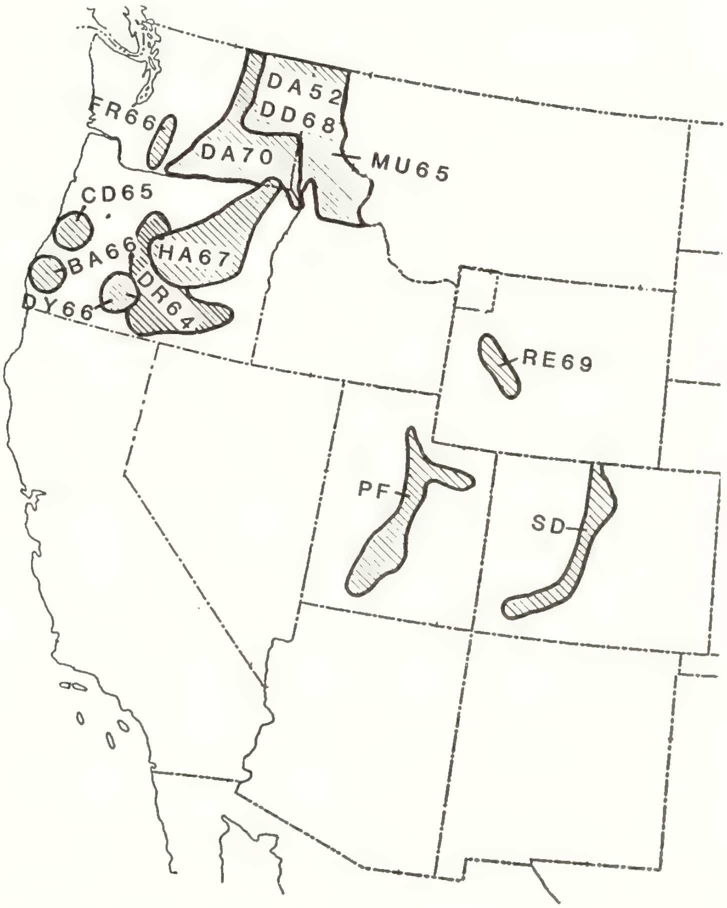

Figure 1--Habitat type classifications in the western United States through 1970. Numbers refer to the year published and letters to the authors, as follows: BA-Bailey, CD-Corliss and Dyrness, DR-Driscoll, DA-Daubenmire, DD-Daubenmire and Daubenmire, DY-Dyrness and Youngberg, FR-Franklin, MU-Mueggler, PF-Pfister, RE-Reed, and SD-Stein and Dix. Letters without numbers refer to classifications under way. Full citations of publications are given in the references.

Table 2--Classifications of habitat types completed in the period 1971-1980 in the western United States, listed by Forest Service region, author, and year completed. The general location of listed studies is shown in figure 2. See references for complete citation

Forest Service region	References
Northern	Mueggler and Stewart 1980, Pfister and others 1977, Roberts 1980, Steele and others 1976.
Rocky Mountain	Boyce 1977, Bunin 1975, Hoffman and Alexander 1976, 1980, Terwilleger and Tiedeman 1978, Tiedeman 1978, Tweit and Houston 1980, Wirsing 1973, Wirsing and Alexander 1975.
Southwestern (Arizona and New Mexico)	Carmichael and others 1978, Hanks and others 1977, Layser and Schubert 1979, Moir and Ludwig 1979.
Intermountain	Cooper 1975, Henderson and others 1976, 1977, Hironaka and Fosberg 1979, Lewis 1971, 1975, Pfister 1972, Reed 1971, 1976, Schlatterer 1972, Steele and others 1975, 1976, 1977, Zamora and Tueller 1973.
Pacific Southwest (California)	Sawyer and Thornburgh 1977.
Pacific Northwest	Dyrness and others 1974, Hall 1973, Henderson 1973, Hines 1971, Hopkins 1979a, 1979b, Tisdale 1979, Volland 1976, Winward and Youtie 1978.

By 1970 in the Intermountain Station, we recognized that a major and costly program was needed to extend habitat type classification as rapidly as possible. Our solution was to assign forest classification as a responsibility of our ecosystem research project. We assigned Bob Pfister as Project Leader and in 1971 entered into a cooperative research and development program with the Northern Region of the Forest Service to develop a habitat type classification for Montana forests. Pfister recruited Steve Arno as an assistant, and the classification program was on its way. The intention was to develop classifications of habitat types and to follow this with classifications of seral communities within habitat types, determine their successional pathways, and assemble a more complete assessment of management implications. Unfortunately, after development of habitat type classifications for several areas, the program lost much of the support needed to accomplish the latter objectives. However, Pfister and others (1977) had included certain management implications in the original classifications.

Additional programs started a year later. The Northern Region requested a similar program on classification of grasslands and shrublands of western Montana. Walter Mueggler, a Project Leader in range research at Bozeman, MT, was assigned by the Intermountain Station to lead this program. A cooperative program between the Station and the Intermountain Region was started in 1972 to develop classification for forest lands in central Idaho. Robert Steele, a student of Fred Johnson at the University of Idaho, was recruited by Pfister to lead this effort as a member of Pfister's unit.

Procedures in these programs evolved with the programs but were generally similar from reconnaissance to the final publications. Sampling methods had been developed by the Daubenmires (1968), Franklin and others (1970), and modified by Pfister and his staff (Pfister and Arno 1980) to facilitate rapid development of a habitat type classification. Analysis of data was similar to that used by Dyrnes and others (1974). Preliminary classifications wer distributed, and land managers were urged to try them and to comment. After 2 or more years, a review draft incorporating comments and new data wa prepared and distributed to use and review. Finall

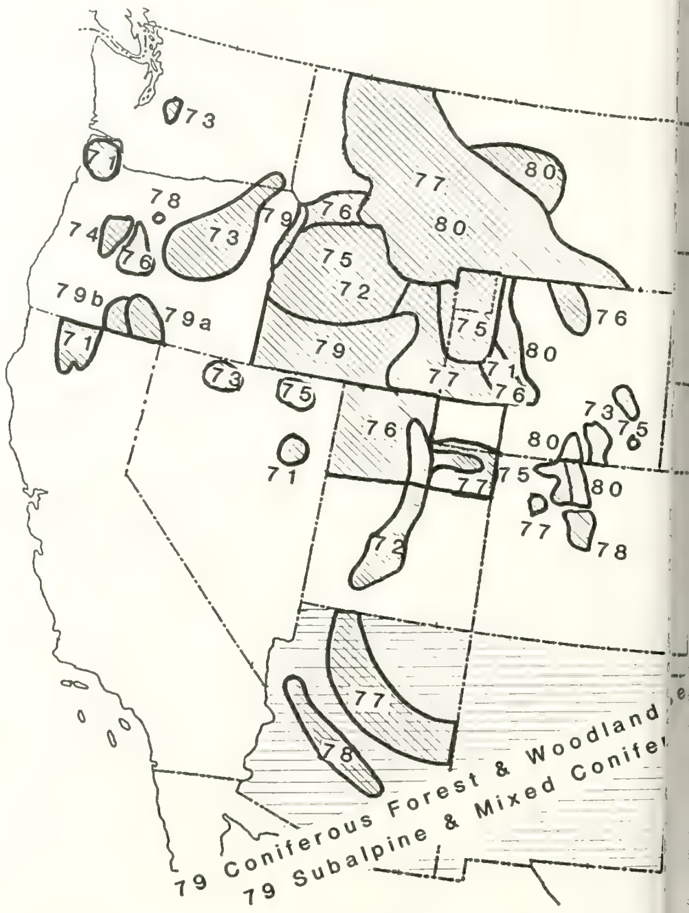

Figure 2--Habitat type classifications in the western United States published during the period 1971 through 1980. Numbers refer to year of publication.

a classification for publication was prepared. Pfister and others (1977) completed a habitat type classification for much of the forest land in Montana, and Roberts (1980) added classification for an additional area in eastern Montana. Mueggler and Stewart (1980) completed and published their classification of grasslands and shrublands of western Montana. Steele and others (1976) issued a preliminary report on classification of forests in the Nez Perce National Forest of northern Idaho. Schlatterer (1972) made preliminary studies of plant associations of central Idaho, and Steele and others (1975) issued a preliminary report on a habitat type classification of central Idaho forests before beginning work in eastern Idaho and western Wyoming and doing the same there (Steele and others 1977). Hironaka and Fosberg (1979) issued a preliminary report on non-forest habitat types in southern Idaho. Cooper (1975) completed his dissertation classification of northwestern Wyoming forests, and Reed (1971, 1976) published his dissertation on forest habitat types of the Wind River Mountains in Wyoming. Pfister (1972) completed his dissertation on classification of high-elevation forests of Utah. Henderson and others (1976) issued a preliminary report on classification of forests in northwestern Utah and another (1977) for forests of the Uinta Mountains. In Nevada, Lewis (1971, 1975) reported on plant associations of two mountain areas, and Zamora and Tueller (1973) published on sagebrush habitat types.

During the 1971 through 1980 period, a number of habitat type classifications were completed in the Rocky Mountain Region, mainly classifications of forests lands but with some exceptions. Work by Boyce (1977), Bunin (1975), Hoffman and Alexander (1976), Terwilleger and Tiedeman (1978), Tiedeman (1978), Tweit and Houston (1980), Wirsing (1973), and Wirsing and Alexander (1975) was reported.

The Southwestern Region also made a start. Hanks and others (1977), Carmichael and others (1978), Layser and Schubert (1979), and Moir and Ludwig (1979) all contributed to the classification program of the Southwestern Region.

The Pacific Southwest Region had one report by Sawyer and Thornburgh (1977) of vegetation types in the Klamath Mountains of California.

In the Pacific Northwest Region, zone ecologists under the direction of Fred Hall began development of classifications of National Forests, and a few reports were issued by the end of the period. These included Hall (1973), Henderson (1973), Hopkins (1979a, 1979b), and Volland (1976). In addition to areas classified by the zone ecologists, other areas were classified by Dyrness and others (1974), Tisdale (1979), Hines (1971) and Winward and Youtie (1978).

In summary, the 1971 through 1980 period was one of major accomplishments in Montana and Idaho and a beginning of efforts with some completions in several other states. Extension of habitat type classifications was by major Forest Service in-service programs and by contracts for smaller areas and an assortment of smaller efforts. Evolution of methodology for rapidly getting the job done marked the period, too.

1981 THROUGH 1987

Table 3 provides a listing of classifications completed during this period, and figure 3 shows where they occurred. The period was marked by a large number of completed classifications--too many to reference in the discussion that follows. New classifications were developed for grasslands and

Table 3--Classifications of habitat types completed in the period 1981-1987 in the western United States, listed by Forest Service region, author, and year completed. The general location of listed studies is shown in figure 3. See references for complete citation

Forest Service Region	Reference
Northern	Arno 1985, Cholewa and Johnson 1983, Cooper and others 1987, Hann 1982, Hansen and Hoffman 1986, Hirsch 1985, Zamora 1982.
Rocky Mountain	Alexander and others 1986, Baker 1982, 1983, DeVelice and others 1986, Hess 1981, Hess and Wasser 1982, Hess and Alexander 1986, Hoffman and Alexander 1983, 1987, Komarkova 1986, Steinauer 1984, Thilenius and Smith 1985.
Southwestern	Alexander and others 1984a, 1984b, 1987, Alexander and Ronco 1987, DeVelice and others 1986, Fitzhugh and others 1987, Hanks and others 1983, Kennedy 1983, Larson and Moir 1986, Moir and Carleton 1987, Muldavin and others 1987a, 1986b, USDA Forest Service 1987a, 1987b.
Intermountain	Gregory 1983, Hironaka and others 1983, Jensen 1987, Mauk and Henderson 1984, Mooney 1985, Mueggler and Campbell 1982, 1986, Nelson and Jensen 1987, Steele and others 1981, 1983, Steele and Geier-Hayes 1983, 1984, 1985a, 1985b, 1986, 1987, Tueller and Eckert 1987, Youngblood and Mueggler 1981, Youngblood and Mauk 1985.
Pacific Southwest	None
Pacific Northwest	Atzet and Wheeler 1984, Brockway and others 1983a, 1983b, Hall 1987, Halvorson and others 1986, Hemstrom and others 1982, 1987, Hemstrom and Logan 1986, Henderson 1982a, 1982b, 1984, Henderson and Peter 1981a, 1981b, Hopkins and Kovalchik 1983, Johnson 1982, Johnson and Simon 1987a, 1987b, Lillybridge 1984, Tisdale 1986, Topik and others 1986, Volland 1985, Williams and Lillybridge 1983, 1987, Yarie 1983.

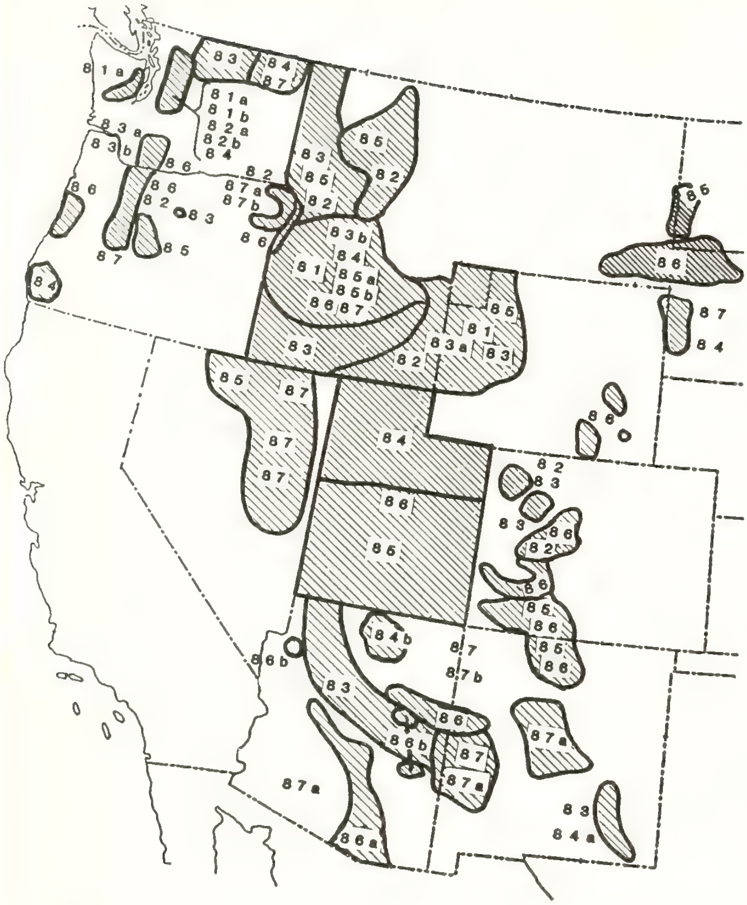

Figure 3--Habitat type classifications in the western United States published during the period 1981 through 1987. Numbers refer to year of publication.

shrublands in the Custer National Forest in southeastern Montana and the adjacent Dakotas. The work in Montana and Idaho was devoted largely to successional studies and classifications of seral stages of certain habitat types. The classification of northern Idaho forests was redone to include habitat types missed in the original classification and to divide certain broad habitat types. Classifications for both coniferous and aspen forests in Utah were completed.

Table 4--Number of habitat type classifications completed in the western United States, by time periods and Forest Service regions

Forest Service region	Through 1970	1971-1980	1981-1987
Northern	4	4	7
Rocky Mountain	0	9	11
Southwestern	0	4	14
Intermountain	1	14	19
Pacific Southwest	0	1	0
Pacific Northwest	6	9	24
Totals	11	41	75

Sagebrush and other mountain shrub vegetation was given attention in Nevada. Classification of most forest lands in Wyoming, Colorado, New Mexico, and Arizona was completed. Most of the classifications in Washington and Oregon were by Hall's zone ecologists. In brief, an impressive number of classifications were completed, many of them for National Forest land.

Table 4, which lists the number of completed classifications by time periods and Forest Service Regions, indicates the steady increase in classification effort.

DISCUSSION

Figure 4 attempts to show habitat type classifications to date. It is somewhat misleading because classification of all lands in areas showing classification is not complete. Even Idaho, which probably is most complete, lacks classifications for alpine areas, certain mountain shrub communities, most wetlands, and salt-desert shrub habitats. In addition, although a start has been made, classification of seral stages within habitat types, their successional pathways, and a more complete assessment of management implications needs to be completed for most habitat types.

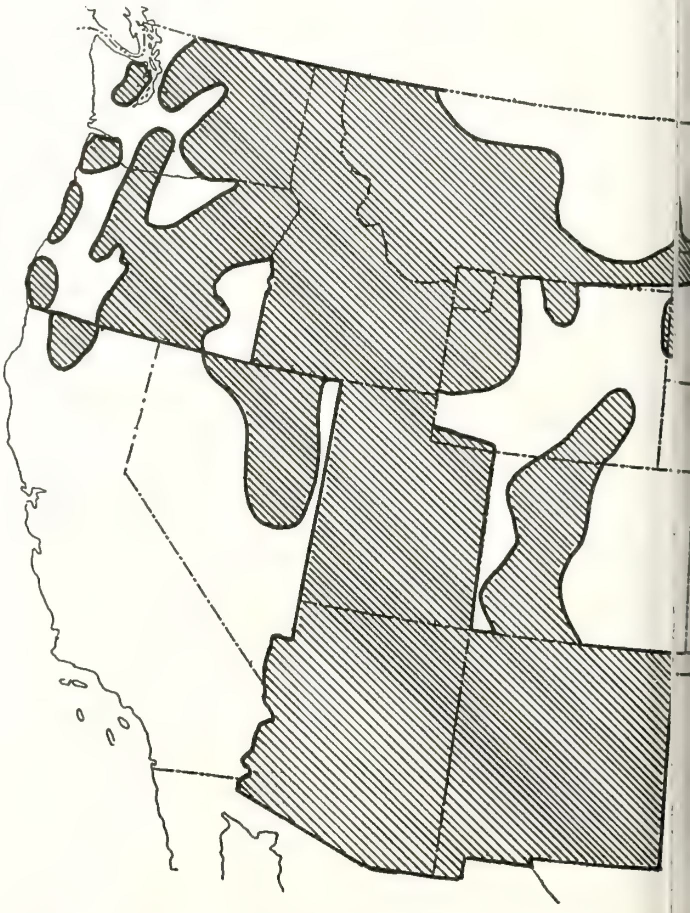

Figure 4--Areas in the western United States where vegetation has been partially or completely classified by habitat types.

Major gaps in classifications in the Northern Region include forests and grasslands in eastern Montana, and alpine areas.

Robert Alexander (1985) has summarized major habitat types, community types, and plant communities in the Rocky Mountains, and Barry Johnston (1987) has published a detailed manual of plant associations of the Rocky Mountain Region of the Forest Service. Johnston (1983) reported a critical need to develop plant association classifications for non-forest lands using a multifactor methodology. He is concerned about incompleteness of some contract classifications and the correlations needed and required between classifications. He prefers complete classifications of all lands in any unit rather than separate classifications for forests, shrublands, grasslands, etc.

Moir (1987) reported that major gaps in classifications for the Southwestern Region are grasslands, deserts, chaparral, and alpine.

In the Intermountain Region, major gaps are pinyon-juniper, salt-desert shrublands, and alpine areas. Classifications are needed for non-forest lands in Utah and Nevada. Winward (1987) stated that the Intermountain Region will depend on the Pacific Southwest Region to develop classifications for Intermountain Region land in California. Duane Lloyd of Intermountain Station informed me that Richard Everett, with Intermountain Station in Reno, is devoting much of his time to the difficult task of developing a classification for pinyon-juniper lands.

Allen and Diaz (poster paper, this proceedings) describe a Federal-State long-term program, begun in 1983, to develop a classification system that will identify ecological types in California. An interagency group meets regularly to assist this program. They will have draft guides for several target types ready by early 1988 for field testing.

The Pacific Northwest Region has largely concentrated on developing plant association classifications for National Forests. Many classifications have been completed but several forests remain to be completed. The Region has gaps in classifications for non-National Forest lands.

WHAT ARE MAJOR CLASSIFICATION NEEDS?

Most Regions have ongoing programs in riparian classification. All Regions have done little in classification of alpine lands and the numerous non-forested subalpine habitats. However, the overall major needs seem to be classification of pinyon-juniper and shrublands in general.

The habitat type concept has experienced greater acceptance by managers of forest land than by managers of range lands. The reason for this probably is that we had no ecological classification system for forest lands, but the range site system (Dyksterhuis 1949), developed before the habitat type system, was available for range managers and was accepted and used. The range site system is an ecological classification based on climax vegetation and other factors. Both Daubenmire (1984) and Hironaka (1986) have written papers on the subject.

In my discussions of classification of range lands with Min Hironaka, Ed Tisdale, and Al Winward, they all agree that classifications by range sites could be incorporated into habitat types, perhaps as subtypes. They point out that classifications by range sites, habitat types, and existing vegetation are needed in range management, and incorporation of range sites into habitat types would provide several advantages.

Some of the Regional Ecologists voiced disappointment that the Forest Service Research Stations have been bowing out of the classification program. Some Stations have scientists engaged in classification, but their work usually is financed by National Forest Administration. In my experience, most classification programs are a mix of research and development. I believe they are best conducted as cooperative programs between the Stations and Regions.

My interest in research natural areas leads me to a comment on the value of habitat types to the natural area selection process. Habitat types have proved invaluable to the research natural area program in selecting areas to include the diversity of vegetation. However, classification by habitat types has not been very helpful in preserving very rare plant associations because classifications usually do not include the rare associations. There are exceptions. For example, Bob Steele and Charlie Johnson usually include mention in their classifications of the rare and incidental types they have encountered even though they may not have sampled them. I would encourage all developers of classifications to do this. The importance of preserving natural diversity in all its forms has not really seeped into the consciousness of a great number of Federal land managers.

CONCLUSIONS AND SUMMARY

The habitat type concept of land classification has experienced periods of development, extension, and acceptance. I find it convenient to break the time into three periods:

Through 1970--This was the period of development of the concept by the Daubenmires. Their classifications were examined, tested, and accepted by scientists and land managers, especially in its area of development. It was a period of training ecologists in the concept, especially by Daubenmire at Washington State University and Poulton at Oregon State University. Their students were critically important to the extension and acceptance of the habitat type concept.

1971 Through 1980--This was a period of extension of the classification concept by the Forest Service through major in-service programs, especially in the Northern, Intermountain, and Pacific Northwest Regions. Extension was also by contracts, mainly with university ecologists for classifications, usually for National Forest areas, especially in the Rocky Mountain Region. University and Forest Service Research Station ecologists were active, also, in developing classifications for other specific lands. It was a period of extension, and evolution of methodology to develop and improve classifications.

1981 Through 1987-This period was marked by payoffs of extension efforts begun in the previous period and by a wave of increased classification efforts, especially in the Rocky Mountain, Southwest, and Pacific Northwest Regions.

Classification by habitat types has been developed for much of the forest land of the western United States. The habitat type concept has been much less accepted among rangeland managers, possibly because the range site system of classification has been widely developed and accepted.

As might be expected, classifications by contract for smaller areas of land require more correlation of classifications than large in-service programs covering large areas. Correlation of classifications is needed in all Regions--in some much more than others.

Classifications have varied in their inclusion of soils, landforms, and seral communitites within habitat types and their successional pathways, and management implications. In general, classifications developing only habitat types require follow-up to classify seral communities within habitat types, and to determine their successional pathways and management implications. Arno (1982) has written an account of the methodology involved. The trend in recent classification programs in eastern Montana, and the Southwest and Pacific Southwest Regions, has been multifactor classifications. Zone ecologists under the leadership of Fred Hall in the Pacific Northwest Region have continued their multifactor classifications.

Development of habitat type classifications has been a great help in research natural area programs in selecting areas to include the range of ecosystem diversity. However, classifications have not been as helpful in preserving rare habitats because these are most often not included in classifications.

Classification of land by habitat types has proved to be very helpful in land management. Land managers, especially foresters, have generally accepted habitat types as an important tool in management. On-the-ground use of habitat types as an aid in prescribing management practices is common in some Regions but not common in others.

Although many gaps in developing classifications for land situations remain, progress is very encouraging. Some of the major jobs ahead are:

-- Completing gaps in classifications.
-- Correlating existing classifications.
-- Developing classifications for seral communities within habitat types and determining their successional pathways and management implications.
-- Refining classifications after gaining experience in their use.
-- Mapping of habitat types.
-- Developing better productivity estimates of each habitat type.
-- Fitting classifications by habitat types into an overall land classification framework.

REFERENCES

Alexander, Billy G., Jr.; Ronco, Frank, Jr.; Fitzhugh, E. Lee; Ludwig, John A. 1984a. A classification of forest habitat types of the Lincoln National Forest, New Mexico. Gen. Tech. Rep. RM-104. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 29 p.

Alexander, Billy G., Jr.; Ronco, Frank, Jr.; White, Alan S.; Ludwig, John A. 1984b. Douglas-fir habitat types of northern Arizona. Gen. Tech. Rep. RM-108. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 13 p.

Alexander, Billy G., Jr.; Fitzhugh, E. Lee; Ronco, Frank, Jr.; Ludwig, John A. 1987. A classification of the forest habitat types of the northern portion of the Cibola National Forest, New Mexico. Gen. Tech. Rep. RM-143. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 35 p.

Alexander, Robert R. 1985. Major habitat types, community types, and plant communities in the Rocky Mountains. Gen. Tech. Rep. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 105 p.

Alexander, Robert R.; Hoffman, George R.; Wirsing, John M. 1986. Forest vegetation of the Medicine Bow National Forest in southeastern Wyoming: a habitat type classification. Res. Pap. RM-271. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 39 p.

Alexander, Robert R.; Ronco, Frank, Jr. 1987. Classification of the forest vegetation on the National Forests of Arizona and New Mexico. Res. Note RM-469. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Arno, Stephen F. 1982. Classifying forest succession on four habitat types in western Montana. In: Proceedings of the symposium on forest succession and stand development research in the Northwest; 1981 March 26; Corvallis, OR. Corvallis OR: Oregon State University, Forest Research Laboratory: 54-62.

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Atzet, T. A.; Wheeler, D. L. 1984. Preliminary plant associations of the Siskiyou Mountain Province. Unpublished. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 96 p.

Bailey, A. W. 1966. Forest associations and a secondary plant succession in the southern Oregon Coast Range. Corvallis, OR: Oregon State University. 164 p. Dissertation.

Bailey, Robert G. 1982. Classification systems for habitat and ecosystems. In: Research on Fish and Wildlife Habitat. Environmental Protection Agency EPA 600/8-82-022, Washington, DC: 16-26.

Baker, W. L. 1982. Natural vegetation of the Piceance Basin. In: Colorado Natural Heritage Inventory: Inventory of the Piceance Basin, Colorado. Report from the Nature Conservancy to USDI Bureau of Land Management, Craig District. Volume 4, Appendix D, 113 p.

Baker, W. L. 1983. Some aspects of the presettlement vegetation of the Piceance Basin, Colorado. Great Basin Naturalist. 43(2): 687-699.

Boyce, D. A. 1977. Vegetation of the south fork of the White River Valley, Colorado. Boulder, CO: University of Colorado. 328 p. Dissertation.

Brockway, Dale G.; Topik, C.; Hemstrom, M. A.; Emmingham, W. H. 1983a. Plant associations and management guide for Pacific silver fir zone, Gifford Pinchot National Forest. R6-Ecol-130a. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 122 p. (desk copy).

Brockway, D. G.; Topik, C.; Hemstrom, M. A.; Emmingham, W. H.; 1983b. Plant associations and management guide for Pacific silver fir zone, Gifford Pinchot National Forest. R6-Ecol-130b. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 76 p. (field copy).

Brown, David, E; Lowe, Charles, H.; Pase, Charles P. 1980. A digitized systematic classification for ecosystems with an illustrated summary of the natural vegetation of North America. Gen. Tech. Rep. RM-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 93 p.

Bunin, J. E. 1975. The vegetation of the west slope of the Park Range, Colorado. Boulder, CO: University of Colorado. 270 p. Dissertation.

Carmichael, R. S.; Knipe, O. D.; Pase, C. P.; Brady, W. W. 1978. Arizona chaparral: plant associations and ecology. Res. Pap. RM-202. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 16 p.

Cholewa, A. F.; Johnson, F. D. 1983. Secondary succession in the *Pseudotsuga menziesii*/ *Physocarpus malvaceus* association. Northwest Science. 57 (4): 234-237.

Cooper, S. V. 1975. Forest habitat types of northwestern Wyoming and contiguous portions of Montana and Idaho. Pullman, WA: Washington State University. 190 p. Dissertation.

Cooper, Stephen V.; Neiman, Kenneth E.; Steele, Robert; Roberts, David W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Corliss, J. F.; Dyrness, C. T. 1965. A detailed soil-vegetation survey of the Alsea area in the Oregon Coast Range. In: Youngberg, C. T., ed. Forest-soil relationships in North America. Corvallis, OR: Oregon State University Press: 457-483.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22(3): 301-330.

Daubenmire, R. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington State University, College of Agriculture, Agriculture Experiment Station. 131 p.

Daubenmire, Rexford. 1984. Viewpoint: Ecological site/range site/habitat type. Rangelands. 6: 263-264.

Daubenmire, R.; Daubenmire, Jean B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, College of Agriculture, Agricultural Experiment Station. 104 p.

DeVelice, Robert L.; Ludwig, John A.; Moir, William H.; Ronco, Frank, Jr. 1986. A classification of forest habitat types of northern New Mexico and southern Colorado. Gen. Tech. Rep. RM-131. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 59 p.

Driscoll, Richard S. 1964. Vegetation--soil units in the central Oregon juniper zone. Res. Pap. PNW-19. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 60 p.

Driscoll, Richard S.; Minkel, Daniel L.; Radloff, David L.; Snyder, Dale E.; Hagihara, James S. 1984. An ecological land classification framework for the United States. Misc. Pub. 1439. Washington, DC: U.S. Department of Agriculture, Forest Service. 56 p.

Dyksterhuis, E. J. 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management. 2(3): 104-155.

Dyrness, C. T.; Franklin, Jerry F.; Moir, W. H. 1974. A preliminary classification of forest communities in the central portion of the western Cascades in Oregon. Bull. No. 4. Seattle, WA: University of Washington, Coniferous Forest Biome. 123 p.

Dyrness, C. T.; Youngberg, C. T. 1966. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ecology. 47: 122-138.

Fitzhugh, E. Lee; Moir, William H.; Ludwig, John A.; Ronco, Frank, Jr. 1987. Forest habitat types in the Apache, Gila, and part of the Cibola National Forests. Gen. Tech. Rep. RM-145. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 116 p.

Franklin, J. F. 1966. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Pullman, WA: Washington State University. 132 p. Dissertation.

Franklin, Jerry F. 1980. Ecological site classification activities in Oregon and Washington. The Forestry Chronicle. 56(2):68-70.

Franklin, Jerry F.; Dyrness, C. T.; Moir, W. H. 1970. A reconnaissance method of forest site classification. Shirin Richi. 12(1): 1-14.

Gregory, Shari. 1983. Subalpine forb community types of the Bridger-Teton National Forest, Wyoming. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 62 p. + appendices.

Hall, F. C. 1967. Vegetation-soil relations as a basis for resource management on the Ochoco National Forest of central Oregon. Corvallis, OR: Oregon State University. 207 p. Dissertation.

Hall, F. C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R-6 Area Guide 3-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 62 p.

Hall, F. C. 1980. Application of a classification system based on plant community types (associations) with special reference to wildlife, range, and timber management. In: The scientific and technical basis for land classification, a joint technical session. Spokane, WA: 1980 October 7; Society of American Foresters: 11-17.

Hall, F. C. 1987. Pacific Northwest ecoclass codes for plant associations. R6-Ecol T.P. 289-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Halverson, N. M., Topik C.; VanSickle, R. 1986. Plant associations and management guide for the western hemlock zone, Mt. Hood National Forest. R6-Ecol 232A 1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 111 p.

Hanks, Jess P.; Fitzhugh, E. Lee; Hanks, Sharon R. 1977. Preliminary habitat types and community types in the ponderosa pine forests of northern Arizona. Unpublished. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hanks, Jess P.; Fitzhugh, E. Lee; Hanks, Sharon R. 1983. A habitat type classification system for ponderosa pine forests of northern Arizona. Gen. Tech. Rep. RM-97. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Hann, Wendel John. 1982. A taxonomy for classification of seral vegetation of selected habitat types in western Montana. Moscow, ID: University of Idaho. 235 p. Dissertation.

Hansen, P. L.; Hoffman, G. R. 1986. The vegetation of the Grand River/Cedar River, Sioux, and Ashland Divisions of the Custer National Forest: a habitat type classification. Vermillion, SD: University of South Dakota, Department of Biology. 255 p.

Hemstrom, Miles A.; Emmingham, W. H.; Halverson, N. M.; Logan, S. E.; Topik, C. 1982. Plant associations and management guide for the Pacific silver fir zone (Mt. Hood and Willamett National Forests). R6-Ecol 100-1982b. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 92 p.

Hemstrom, M. A.; Logan, S. E. 1986. Plant associations and management guide for the Siuslaw National Forest. R6-Ecol 22 1986a. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 121 p.

Hemstrom, M. A.; Logan, S. E.; Pavlat, W. 1987. Plant associations and management guide for the Willamette National Forest. R6-Ecol- 257-1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 312 p

Henderson, J. A. 1973. Composition, distribution and succession of subalpine meadows in Mt. Rainier National Park, Washington. Corvallis, OR: Oregon State University. 150 p. Dissertation.

Henderson J. A. 1982a. Plant associations and habitat types of the Skykomish River Drainages, Mt. Baker-Snoqualmie National Forest. Unpublished. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 88 p.

Henderson, J. A. 1982b. Succession in two habitat types in western Washington. In: Proceedings o the symposium on forest succession and stand development research in the Northwest; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 80-86.

Henderson, J. A. 1984. Plant associations and habitat types of the Darrington Ranger Distric Mt. Baker-Snoqualmie National Forest. Unpublished. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 69 p.

Henderson, J. A.; Mauk, R. L.; Anderson, D. L.; Ketchie, P. L.; Simon, S.; Sperger, R. H.; Young, R. W.; Youngblood, A. 1976. Preliminary forest habitat types of northwestern Utah and adjacent Idaho. Unpublished. Logan, UT: Utah State University, Department of Forestry and Outdoor Recreation. 94 p.

Henderson, J. A.; Mauk, R. L.; Anderson, D. L.; Davis, T. A.; Keck, T. J. 1977. Preliminary forest habitat types of the Uinta Mountains, Utah. Unpublished. Logan, UT: Utah State University, Department of Forestry and Outdoor Recreation. 94 p.

Henderson, J. A.; Peter, D. 1981a. Plant associations and habitat types of the Shelton Ranger District, Olympic National Forest. Unpublished. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 110 p.

Henderson, J. A.; Peter, D. 1981b. Plant associations and habitat types of the White River Ranger District, Mt. Baker-Snoqualmie National Forest. Unpublished. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 110 p.

Hess, K. 1981. Phyto-edaphic study of habitat types of the Arapaho-Roosevelt National Forest, Colorado. Fort Collins, CO: Colorado State University. 558 p. Dissertation.

Hess, K.; Wasser, C. H. 1982. Grassland, shrubland, and forestland habitat types of the White River-Arapaho National Forest. Final Report, cooperative agreement no. 53 82FT 1-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station. 335 p.

Hess, K.; Alexander, R. R. 1986. Forest vegetation of the Arapaho and Roosevelt National Forests in central Colorado: a habitat type classification. Res. Pap. RM-266. Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station. 48 p.

Hines, W. W. 1971. Plant communities in the old-growth forests of north coastal Oregon. Corvallis, OR: Oregon State University. 146 p. Dissertation.

Hironaka, M. 1986. Habitat type, range site, and community type. In: Proceedings; Symposium on the biology of Artemisia and Chrysothamnus, 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 15-18.

Hironaka, M.; Fosberg, M. A. 1979. Nonforest habitat types of southern Idaho, interim report. Moscow, ID: University of Idaho; College of Forestry, Wildlife and Range Sciences; Forest, Wildlife and Range Experiment Station. 206 p.

Hironaka, M.; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bull. No. 35. Moscow, ID: University of Idaho; College of Forestry, Wildlife and Range Sciences; Forest, Wildlife and Range Experiment Station. 44 p.

Hirsch, K. J. 1985. Habitat type classification of grasslands and shrublands of southwestern North Dakota. Fargo,ND: North Dakota State University. 281 p. Dissertation.

Hoffman, George R.; Alexander, Robert R. 1976. Forest vegetation of the Bighorn Mountains, Wyoming: a habitat type classification. Res. Pap. RM-170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.

Hoffman, G. R.; Alexander, R. R. 1980. Forest vegetation of the Routt National Forest in northwestern Colorado: a habitat type classification. Res. Pap. RM-221. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 41 p.

Hoffman, G. R.; Alexander, R. R. 1983. Forest vegetation of the White River National Forest in western Colorado: a habitat type classification. Res. Pap. RM-249. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

Hoffman, George R.; Alexander, Robert R. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. Res. Pap. RM-276. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 49 p.

Hopkins, W. E. 1979a. Plant associations of the Fremont National Forest. R6-Ecol-79-004. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 106 p.

Hopkins, W. E. 1979b. Plant associations of South Chiloquin and Klamath Ranger Districts, Winema National Forest. R6-Ecol-79-005. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 106 p.

Hopkins, William E.; Kovalchik, Bernard L. 1983. Plant associations of the Crooked River National Grassland. R6-Ecol-133-1983, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 98 p.

Jensen, M. E. 1987. A sagebrush community-type classification for mountainous northeastern Nevada rangelands. Unpublished. 30 p.

Johnson, Charles G. 1982. An interpretation of synecologic relationships in the Billy Meadows area of the Wallowa-Whitman National Forest. Corvallis, OR: Oregon State University. 381 p. Dissertation.

Johnson, Charles G., Jr.; Simon, Steven A. 1987a. Plant associations of the Wallowa-Snake Province, Wallowa-Whitman National Forest. R6-Ecol TP 255A 86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 399 p.

Johnson, Charles G., Jr.; Simon, Steven A. 1987b. Plant associations of the Wallowa-Snake Province, Wallowa-Whitman National Forest. R6-Ecol TP 255B 86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 272 p.

Johnston, Barry C. 1983. Regional correlations among vegetation classification studies. In: Proceedings of the workshop on southwestern habitat types; 1983, April 6-8; Albuquerque, NM. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 96-101.

Johnston, Barry C. 1987. Plant associations of Region 2. R2-Ecol-87-2. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 427 p.

Kennedy, Kathyrn L. 1983. A habitat type classification of the pinyon-juniper woodlands of the Lincoln National Forest, New Mexico. In: Moir, W. H.; Hendzel, Leonard, Tech. Coordinators. Proceedings of the workshop on southwestern habitat types. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 54-61.

Komarkova, V. 1986. Habitat types on selected parts of the Gunnison and Uncompahgre National Forests. Final Report to U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 270 p. + appendices.

Larson, Milo; Moir, W. H. 1986. Forest and woodland habitat types (plant associations) of southern New Mexico and central Arizona (north of the Mogollon Rim). Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 121 p.

Layser, E. F.; Schubert, G. H. 1979. Preliminary classification for the coniferous forest and woodland series of Arizona and New Mexico. Res. Pap. RM-208. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 27 p.

Lewis, Mont E. 1971. Flora and major plant communities of the Ruby-East Humboldt Mountains with specific emphasis on Lamoille Canyon. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Humboldt National Forest. 62 p.

Lewis, Mont E. 1975. Plant communities of the Jarbridge Mountain complex, Humboldt National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 22 p.

Lillybridge, Terry R. 1984. Forested plant associations of the Colville National Forest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 153 p. Draft.

Mauk, Ronald, L.; Henderson, Jan A. 1984. Coniferous forest habitat types of northern Utah. Gen. Tech. Rep. INT-170. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 89 p.

Moir, William H. 1987. (Personal communication). October 12. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Moir, William H.; Ludwig, John A. 1979. A classification of spruce-fir and mixed conifer habitat types of Arizona and New Mexico. Res. Pap. RM-207. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 47 p.

Moir, William H.; Ludwig, John A. 1983. Methods of forest habitat type classification. In: Proceedings of the workshop on southwestern habitat types; 1983 April 6-8; Albuquerque, NM. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 5-10.

Moir, W. H.; Carleton, J. C. 1987. Classification of pinyon-juniper (P-J) sites on National Forests in the Southwest. In: Everett, Richard, compiler. Proceedings; pinyon-juniper conference. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 216-226.

Mooney, Melissa Jane. 1985. A preliminary classification of high elevation sagebrush-grass vegetation in northern and central Utah. Reno, NV: University of Nevada. 123 p. Thesis.

Mueggler, Walter F. 1965. Ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. Ecological Monographs. 35: 165-185.

Mueggler, W. F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Mueggler, Walter F.; Campbell, Robert B., Jr. 1982. Aspen community types on the Caribou and Targhee National Forests in southeastern Idaho. Res. Pap. INT-294. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Mueggler, Walter R.; Campbell, Robert B. 1986. Aspen community types of Utah. Res. Pap. INT-362. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 69 p.

Muldavin, Esteban; DeVelice, Robert L.; Dick-Peddie, William. 1986a. Forest habitat types of the Prescott, Tonto, and western Coronado National Forests. (Final Rep. CA 28 K3 307, on file). Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory.

Muldavin, Esteban; DeVelice, Robert L.; Dick-Peddie, William. 1986b. Forest habitat types of the Fort Apache, San Carlos, and Hualapi Indian Reservation, Arizona. Final Rep. Coop. Agreement Addendum 28 K3 307. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 67 p.

Nelson, Lynda Peck; Jensen, Mark E. 1987. Sagebrush grass community types of the Humboldt National Forest. Unpublished. 80 p.

Pfister, R. D. 1972. Vegetation and soils in the subalpine forests of Utah. Pullman, WA: Washington State University. 98 p. Dissertation.

Pfister, R. D. 1977. Ecological classification of forest land in Idaho and Montana. In: Proceedings ecological classification of forest land in Canada and northwestern USA. Vancouver, BC: University of British Columbia: 329-358.

Pfister, R. D. 1982. Designing succession models to meet management needs. In: Proceedings of the symposium on forest succession and stand development research in the northwest; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 44-53.

Pfister, R. D.; Corliss, John C.; and others. 1973. Ecoclass--a method for classifying ecosystems--a task force report to the Chief of the Forest Service. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 52 p.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Pfister, Robert D.; Arno, Stephen F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26(1): 52-70.

Reed, R. M. 1969. A study of vegetation in the Wind River Mountains, Wyoming. Pullman, WA: Washington State University. 77 p. Dissertation.

Reed, R. M. 1971. Aspen forests of the Wind River Mountains, Wyoming. American Midland Naturalist. 86: 327-343.

Reed, R. M. 1976. Coniferous forest habitat types of the Wind River Mountains, Wyoming. American Midland Naturalist. 95: 159-173.

Roberts, D. W. 1980. Forest habitat types of the Bear's Paw Mountains and Little Rocky Mountains, Montana. Missoula, MT: University of Montana. 120 p. Thesis.

Sawyer, J. O.; Thornburgh, D. A. 1977. Montane and subalpine vegetation of the Klamath Mountains. In: Barbour, M. C.; Major, J. eds. Terrestrial vegetation of California: 699-732. New York: John Wiley and Sons. 1,002 p.

Schlatterer, Edward F. 1972. A preliminary description of plant communities found on the Sawtooth, White Cloud, Boulder, and Pioneer Mountains. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 111 p.

Schlatterer, Edward F. 1983. Forest ecosystem classification and interpretation for management of multiple uses in forest and rangeland environments. In: Proceedings of the workshop on southwestern habitat types; 1983 April 6-8; Albuquerque, NM. Albuquerque NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 1-4.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. 1975. Forest habitat types of central Idaho. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. Review Draft of Intermountain Station Publ. 191 p.

Steele, Robert; Arno, Stephen F.; Pfister, Robert D. 1976. Preliminary forest habitat types of the Nezperce National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 71 p.

Steele, R.; Ondov, D.; Cooper, S. V.; Pfister, R. D. 1977. Preliminary forest habitat types of eastern Idaho and western Wyoming. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. 147 p. mimeo.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Steele, Robert; Cooper, Stephen V.; Ondov, David M.; Roberts, David W.; Pfister, Robert D. 1983. Forest habitat types of eastern Idaho--western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

Steele, Robert; Geier-Hayes, Kathleen. 1983. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Preliminary draft. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. 83 p.

Steele, Robert; Geier-Hayes, Kathleen. 1984. The Douglas-fir/pinegrass habitat type in central Idaho: succession and management. Preliminary draft. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. 124 p.

Steele, Robert; Geier-Hayes, Kathleen. 1985a. The grand fir/mountain maple habitat type in central Idaho: succession and management. Preliminary draft. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. 118 p.

Steele, Robert; Geier-Hayes, Kathleen. 1985b. The grand fir/huckleberry habitat type in central Idaho: succession and management. Review draft. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Intermountain Region. 90 p.

Steele, Robert; Geier-Hayes, Kathleen. 1986. The Douglas-fir/white spiraea habitat type in central Idaho: succession and management. Preliminary draft. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station and Intermountain Region. 96 p.

Steele, Robert; Geier-Hayes, Kathleen. 1987. The Douglas-fir/elk sedge habitat type in central Idaho: succession and management. Preliminary draft. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 111 p.

Steen, O. A.; Dix, R. L. 1970. (Cooperative study of subalpine forests in Colorado with U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Initiated in 1970.) Fort Collins, CO: Colorado State University.

Steinauer, G. A. 1984. A classification of the Cercocarpus montanus, Quercus macrocarpa, Populus tremuloides, and Picea glauca habitat types of the Black Hills National Forest. Vermillion, SD: University of South Dakota. 95 p. Thesis.

Stewart, W. L.; Hann, W. J. 1983. Classification of shrub-steppe habitat in the Northern Rocky Mountains. In: Proceedings of the workshop on southwestern habitat types; 1983 April 6-8; Albuquerque, NM. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 11-20.

Terwilleger, C., Jr.; Tiedeman, J. A. 1978. Habitat types of the mule deer critical winter range and adjacent steppe region of Middle Park, Colorado. Final report. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 108 p.

Thilenius, John F.; Smith, Dixie R. 1985. Vegetation and soils of an alpine range in the Absaroka Mountains, Wyoming. Gen. Tech. Rep. RM-121. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 18 p.

Tiedeman, J. A. 1978. Phyto-edaphic classification of the Piceance Basin. Fort Collins, CO: Colorado State University. 281 p. Dissertation.

Tisdale, E. W. 1979. A preliminary classification of Snake River Canyon grasslands of Idaho. Station Note No. 32. Moscow, ID: University of Idaho; College of Forestry, Wildlife and Range Sciences; Forest Wildlife and Range Experiment Station. 8 p.

Tisdale, E. W. 1986. Canyon grasslands and associated shrublands of west-central Idaho and adjacent areas. Bull. No. 40. Moscow, ID: University of Idaho; College of Forestry, Wildlife and Ranges Sciences; Forest, Wildlife and Range Experiment Station. 42 p.

Topik, C.; Halverson, N. M.; Brockway, D. G. 1986. Plant associations and management guide for the western hemlock zone, Gifford Pinchot National Forest. R6-Ecol 230A 1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 133 p.

Tueller, Paul T.; Eckert, Richard E., Jr. 1987. Big sagebrush (Artemisia tridentata vaseyana) and longleaf snowberry (Symphoricarpos oreophilus) plant associations in northeastern Nevada. Great Basin Naturalist. 47(1): 117-131.

Tweit, S. J.; Houston, K. E. 1980. Grassland and shrubland habitat types of the Shoshone National Forest. Cody, WY: U.S. Department of Agriculture, Forest Service, Shoshone National Forest. 143 p.

USDA Forest Service. 1987a. Forest and woodland habitat types (plant associations) south of the Mogollon Rim, Arizona. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

USDA Forest Service. 1987b. Forest and woodland habitat types (plant associations) of northern New Mexico and northern Arizona. Edition 2. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Volland, L. A. 1976. Plant communities of the central Oregon pumice zone. R-6 Area Guide 4-2. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 113 p.

Volland, L. A. 1985. Plant associations of the central Oregon pumice zone. R6-Ecol-104 1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 138 p.

Westveld, Marinus. 1951. Vegetation mapping as a guide to better silviculture. Ecology. 32: 508-517.

Wertz, W. A.; Arnold, J. F. 1972. Land system inventory. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 12 p.

Williams, Clinton K.; Lillybridge, Terry R. 1983. Forested plant associations of the Okanogan National Forest. R6-Ecol-132. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 116 p.

Williams, C. K.; Lillybridge, T. R. 1987. Forested plant associations of the Colville National Forest. R6-Ecol. Tech. Pap. 292-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 139 p.

Winward, A. H.; Youtie, B. A. 1978. Community analysis of higher plants on the Lawrence Memorial Grassland Preserve. Oregon Academy of Science. 14: 50-65.

Winward, A. H. 1987. (Personal communication). October 15. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Wirsing, J. M. 1973. Forest vegetation in southeastern Wyoming. Pullman, WA: Washington State University. 170 p. Thesis.

Wirsing, J. M.; Alexander, R. R. 1975. Forest habitat types on the Medicine Bow National Forest, southeastern Wyoming: preliminary report. Gen. Tech. Rep. RM-12. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.

Yarie, J. 1983. Forest community classification of the Porcupine River drainage, interior Alaska, and its application to forest management. Gen. Tech. Rep. PNW-154. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 68 p.

Youngblood, Andrew P.; Mueggler, Walter F. 1981. Aspen community types on the Bridger-Teton National Forest in western Wyoming. Res. Pap. INT-272. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Youngblood, Andrew P.; Mauk, Ronald L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

Zamora, B.; Tueller, P. T. 1973. Artemisia arbuscula, A. longiloba, and A. nova habitat types in northern Nevada. Great Basin Naturalist. 33 (4): 255-264.

Zamora, Benjamin A. 1982. Understory development in forest succession: an example from the inland Northwest. In: Proceedings of the symposium on forest succession and stand development research in the northwest; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory. 63-39.

BASIC CONCEPTS OF USING VEGETATION TO BUILD A SITE CLASSIFICATION SYSTEM

Robert D. Pfister

ABSTRACT: Three kinds of concepts are reviewed. Basic ecological concepts are critical to understanding vegetation-site interrelationships. Classification concepts are helpful to make meaningful comparisons among different classification approaches and uses. Application concepts are necessary to ensure optimum use of the ecological classifications in natural resource management.

INTRODUCTION

This symposium is possible only because vegetation based site systems are now available for much of the land area in the western United States and because they have been widely employed in various fields of natural resource management.

The basic ecological concepts or ideas underlying the systems are found in many textbooks, classification monographs, and numerous publications. The basic concepts of classification, per se, are less readily available, while the basic concepts of applying the classification systems to natural resource management are still evolving.

Managers can, and often do, use classifications as a "cook-book" approach, without fully understanding the basic concepts. However, a true understanding of a few fundamental concepts allows the user to go beyond the mechanical aspects and enjoy some true understanding of ecosystems.

Concepts are ideas, as distinguished from perceptions. We each see things from one point of view --our own! This paper is my perception, but I am searching for the perceptions that I believe are held in common by a large number of people here. Different perceptions of the same object or subject lead to vigorous debate that can be productive, destructive, or simply noisy. My goal is to document the common foundation, the common denominator, that has led to widespread acceptance and application of vegetation-based site classification in this part of the world. This common perception represents the basic concepts.

To achieve this goal, I will need to condense and simplify--perhaps to the chagrin of some intellectual purists. However, simplification is essential for communication--and communication is essential for transfer of knowledge. The fact that large numbers of natural resource specialists are successfully applying ecological classifications illustrates the achievement of a common level of understanding and communication.

One definition describes science as the process of developing knowledge through four basic steps: (1) observation, (2) description, (3) classification and (4) abstraction. Ben Stout, the former Dean of the School of Forestry at the University of Montana, used to "twist my tail" continuously in reference to the status of habitat type classification. He pointed out that we had completed step three for some areas, but when were we going to do step four? Naturally this challenge has been a "burr under my saddle," leading me to look beyond classification to the final step.

I went to dictionaries for a better understanding of *abstraction* and found many meanings:

1. To separate or extract--to consider separately.
2. Mathematics--a group without regard to character of elements.
3. Expressing a property apart from the real object or thing.
4. Theoretical--apart from practical or actual conditions--the realm of pure science as opposed to applied science.
5. Not easily understood--*abstruse.*
6. To summarize or condense.

I also stumbled across the term *abstracted,* which means lost in thought and unaware of physical surroundings and realities. You have all met abstracted people--one synonym is "absent-minded". The charitable thing to do is to assume that all those "absent-minded" professors that you put up with were actually totally involved in the final step of science--abstraction!

So now I invite you to take a little trip with me into the never-never land of abstraction, forgetting where we are, who we are, and who is sitting beside us. Let us put on our thinking caps and spend 20 minutes on a couple of questions. What is all this classification stuff really about? Where are these ecologists coming from? My hope is that several of you will be able to say "Aha!" "Something clicks!" or "Now I understand!".

Since the focus of this symposium is on applications to natural resource management, I will not

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Robert D. Pfister is Research Professor, School of Forestry, University of Montana, Missoula, MT.

concentrate on indepth discussion of any theoretical aspects. Rather, I will attempt to:

1. Separate and review the basic ideas embodied in vegetation-based site classification.
2. Link these ideas for understanding of theoretical aspects (with some real examples).
3. Summarize or condense these basic concepts for general understanding at a common level. In other words, to provide a concentrated essence of a larger whole.

The subject matter of this symposium spans three major groups of professionals:

1. The developers--a few (10's of people) ecological specialists wrestling with theory and data to produce a taxonomy of natural vegetation types as integrated expressions of ecosystem diversity.
2. The application specialists--the several (10's to 100's of people) natural resource specialists involved with analyzing, interpreting and reporting natural resource information in relation to the classification system.
3. The users--the many (100's to 1000's of people) regularly identifying and mapping vegetation types and using natural resource knowledge related to the types.

All of the above will make better use of the powerful tool of classification if they share a common understanding of the basic concepts. Herein lies the challenge of making the complex appear simple --the abstraction of the simple elegance of using vegetation types as an integrated expression of the physical environment.

Through experience, I have learned that it is easier to convey the basic concepts to lay people than to many professionals. This can be described as resistance to learning, an acquired characteristic of our society and even of some of our educational approaches. An open mind is a prerequisite for consideration of new ideas before they are weighed against existing individual perception. My point is--take a trial ride with my perception --weigh it against your own--if we agree, we have achieved a common concept--a shared idea. If we disagree, we have food for more thought and discussion.

Conveying concepts with words alone is difficult, especially with the English language (illustrated by my search for definitions of *abstraction*). Mathemeticians resort to equations or functional expressions. I have found pictures or figures extremely useful in illustrating concepts and will use those that have been most helpful to my own understanding and teaching.

BASIC ECOLOGICAL CONCEPTS

1. The Ecosystem Concept (Tansley 1935)--A broad perspective emphasizing that all organisms and their environment are inter-related. This may be portrayed as a multi-dimensional web or as a diagram of structural components (fig. 1). Synonyms are shown to help avoid confusion in terminology.

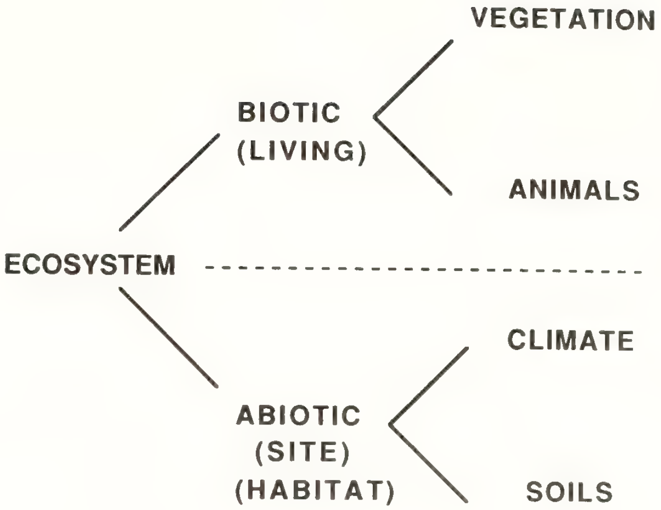

Figure 1--A hierarchical illustration of the components of an ecosystem (with synonymy).

From left to right, we separate the biotic (living) components from the abiotic (nonliving) that we call the *physical environment*, or *habitat*, or *site*. The next subdivision (four major components) is a focal point for vegetation-based site classification. This is where we interpret vegetation as a reflection of the other three components.

2. Vegetation is an Integrated Expression of Physical Environment (and Animals and Time and Treatments)--(Daubenmire 1952, 1968).

Vegetation = f (Flora, Climate, Topography, Soils, Animals, Time, and Treatments)

The occurrence of plants in a given place is controlled by available species, competition over time, and all factors of the ecosystem. In order to use vegetation as a land classification system, one must hold certain factors constant to study relations among the others. This has been done effectively by selecting sample stands for study that:

a. are within a specific region (control of Flora),
b. are not strongly influenced by grazing (control of Animal),
c. are natural stands (control of Treatment),
d. have reached a degree of stability (control of Time).

These are the stands that reflect the combined effects of Climate, Topography (microclimate), and Soils.

3. The Natural Climax Community Best Reflects Environmental Potentials (Daubenmire 1981)--The concept of climax as a stable, self-regenerating permanent entity is a subject of ecological debate. Nevertheless, acceptance of a degree of stability reached in the process of secondary succession is common to most vegetation-based site classifications. The terms "potential natural vegetation,"

"stable, late-seral," "near-climax" or a special definition of "community type" are often used where "climax" is difficult to determine or to defend with concrete examples. Although complex and difficult to define precisely, the concept is essential. Difficulties in definition need not be a roadblock for developing practical, operational vegetation-based site classification systems.

4. The Time Frame for Climax is Relatively Short.--Most operational, vegetation-based site classifications are based on interpretation of climax as a late, stable stage of secondary succession. In forest conditions, this stage is reached as seral trees are replaced by ones with greater understory tolerance--a period of 200-500 years in the Rocky Mountains. Trends in tree competition are readily interpretable from stand table data, and undergrowth species composition stabilizes relatively early under the forest canopy. This leads to a fair degree of confidence in interpreting the potential climax composition and defining types. Interpretation of climax is related to current climatic and site conditions rather than speculation on unpredictable long-term changes in either climate or site (due to primary succession).

5. The Association is the Basic Unit of Vegetation Classification.--The *plant association* is the abstract, taxonomic unit defined by the ecologist's intuition. It is based on grouping of similar late-successional stands by two major criteria:

a. stands having similar vegetation composition, as determined by synthesis table examination, evaluation of differential or character species, numerical analyses, interaction with other ecologists, and accumulated autecological and synecological understanding of the study area and species, and

b. observation of commonly occurring ecotones or transitions between types in the field.

The term *association* is generally accepted and widely used as having some degree of floristic and physiognomic uniformity, due to uniform *habitat* conditions. Some of us simply define *association* as *climax plant community type*, recognizing that the degree of uniformity and the number of types (lumpers vs. splitters) is a matter of judgment for each individual syntaxonomist, relative to the diversity of each geographic area.

6. The Habitat Type is the Basic Unit of Site Classification (Daubenmire 1952)--Once the associations are defined, a key can be constructed to identify the potential climax type for most successional plant communities. This enables users to recognize all land areas capable of supporting a specific association. This is the strength of the system that has led to widespread application for natural resource management. Sites (habitat types) can be identified for individual resource inventory points, and maps can be constructed by locating the ecotones that represent transition from one habitat type to another.

7. Vegetation Varies With Time and Space--This is one of the oldest and most elemental concepts, but is still very useful to illustrate the interrelationships between the *association* and the *habitat type*. This illustration (fig. 2) is limited to natural vegetation, without consideration of grazing, frequent fire or management treatments (which would require additional dimensions). If w represent all natural vegetation in two dimensions, one for successional stages (time) and the other for a generalized environmental gradient (space), we can illustrate the process of developing a habitat type taxonomy:

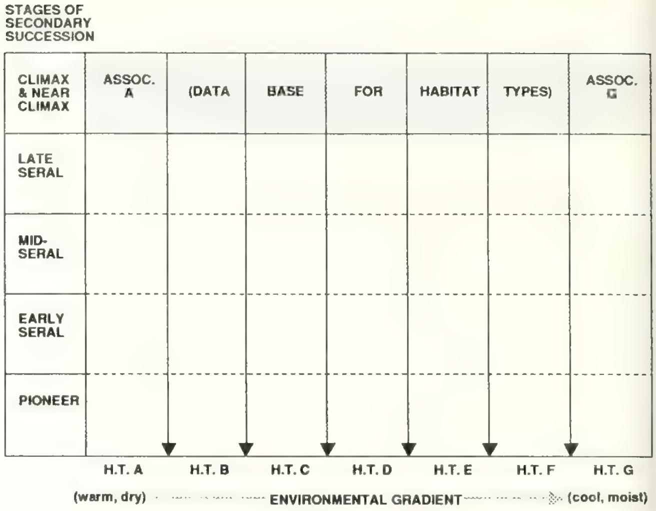

Figure 2--Vegetation variation in time and space illustrating association and habitat type concepts.

a. Sampling the oldest (late successional) stands available on the landscape, which may represent late-seral, near-climax, or occasionally, even climax conditions.

b. Grouping of similar stands (projected towar climax) defines the associations.

c. Arranging them from left to right displays their relative positions along a generalized environmental gradient.

d. Constructing a key that will work with most successional stages extends the vertical line to define the columns, and thereby the habitat types.

The upper row represents the defined associations. The columns include all successional stages leadin toward a specific *association*, and represent the subdivisions of the physical environment we call *habitat types*.

Thus, we can visualize the *habitat type* as representing all the land area capable of supporting, at climax, a specific *association*. (The figure also illustrates the lack of data for defining earlier successional stages; the dotted lines are very general approximations of successional stages.)

8. Nomenclature Can Be a Source of Confusion.--The first problem we have created and continue to promulgate is the fact that we use the same name for two different things--the association and the habitat type. This is defensible because of the

intricate linkage between the two, but it is usually confusing to the student. It may be helpful to explain that there are two classifications in one. The first, the vegetation type (association), provides the basis for the second, the site classification (habitat type). When we say *Pseudotsuga/Physocarpus,* we haven't communicated anything until we add the noun of *association* or *habitat type*!

Another apparent problem is the desire of some ecologists to make the name more descriptive by adding multiple species. This will add specificity, but it also adds the burden of length for the user who has to write it down or say it regularly.

Another problem for some people is that short-hand jargon or numbers are often used for types for ease of communication or analysis--sometimes to the point that "outsiders" feel they are hearing a foreign language. While these extremes may be frustrating, they are really matters of communication protocol and should have little bearing on the basic concepts of classification or application.

9. Principle of Competitive Exclusion- Rule of Monospecific Dominance (Daubenmire and Daubenmire 1968)--The principle of one species eliminating another species completely is rare in plant communities. Rather, a trend toward one species gaining dominance over another is more realistic. The nomenclature of asssociations suggests a single-tree species climax, but minor climax or even co-climax status is maintained by a second species in several defined associations. Crawford and Johnson (1985) document dominance of a "short-tree", *Taxus brevifolia* within part of what other authors describe as the *Abies grandis* series. This may be a point of debate regarding the exact definition of climax composition, but has little effect on the application of habitat types as a site classification system.

10. Hierarchies--Convenience or Dogma?--The size of an *association* is left to the judgment of the individual ecologist developing the taxonomy. These ecologists refer to each other as "lumpers" or "splitters!" *Associations* are commonly grouped (based on the same upper layer of climax dominant species) and termed *series. Associations* can also be subdivided into *phases* to reflect minor differences. Crawford and Johnson (1985) provide a good review of hierarchies and terminology and suggest tightening up the specificity of both.

Although the ecologist using a specific hierarchy may feel it is the most logical and best way to split or group types, we have observed other specialists regrouping our types in different combinations more defensible for their specific needs or objectives. This represents another situation where the grouping/splitting conventions should not be considered critical to the basic classification concepts. Unless used as dogma, it also should not be critical for application concepts.

11. The Principle of Factor Interaction or Compensating Factors--The fact that similar vegetation can occur on a variable range of interacting site factors illustrates interaction or compensation of one factor for another. This principle is critical for meaningful communication among soil scientists and plant ecologists. (It also would provide a good focal point for the current *Range Site* vs. *Habitat Type* debates.) Acceptance of the principle allows one to infer or hypothesize the influence of major factors determining the distribution of habitat types on the landscape.

12. The Polyclimax Concept (Tansley 1935)--This links the concept of relatively short-term climax and the principle of factor compensation in the definition of three *primary climaxes--climatic, topographic and edaphic*. Most associations can occur as a representation of macroclimate on gentle topography and "normal" soils, thereby reflecting a *climatic zone*. The fact that the same association can occur both as a climatic climax and as an edaphic or topographic climax in another macroclimatic zone illustrates *factor compensation*. Some associations are even restricted to unique topographic (micro-climatic) or edaphic situations. For example, the *Pinus contorta/Purshia tridentata* habitat type in the vicinity of West Yellowstone is an example of a unique *topo-edaphic* climax potential (Pfister and others 1977).

The primary climax potentials (associations) represent the complete upper row in figure 2 and all the land area included in a study area. As such, they form the foundation of the habitat type classification. However, other stable plant communities can be found if the factors of prolonged heavy grazing or regular, frequent fires or other regular additional modifications of the system are added. These are termed *secondary climaxes* or *disclimaxes* and would need to be shown as a third dimension in figure 2.

13. Succession--Primary and Secondary--We all have been schooled in the basics of primary plant succession--with pioneer species changing the environment to allow secondary species invasion (generally over a very long time period). We have looked at examples of hydrarch and xerarch succession and must recognize that the slow process of primary succession is continuous, even if we cannot see it and do not measure it. Although primary succession cannot be ignored, it is not critical to upland site classification and management applications, unless management treatments are severe enough to erode soil or initiate a primary succession.

Our area of immediate concern is really secondary succession--the changes in vegetation in response to common disturbances such as fire, insects, disease, windthrow, logging and other vegetative manipulation treatments. This range of possible treatments means it is necessary to add at least one more dimension to our basic figure 2. One approach is to take a single column (habitat type) out of figure 2 and depict multiple successional pathways leading toward (or away from) climax. These may take the form of triangles, cones, or pyramids, as will be illustrated in later papers in this symposium.

Holding environment constant through the use of habitat types aids in understanding of the time and treatment relations of vegetation change (and also serves as a test of the environmental subdivisions of the habitat types).

14. The Plant Association Has a Narrower Ecological Amplitude Than Most Individual Species (Daubenmire 1981)--The bar diagram illustrating relative amplitudes of tree species was first used by Daubenmire (1966) relative to discussion of the continuum concept. Foresters liked the illustration, especially the shaded portion of the tree species range used to illustrate where it would be climax, thereby illustrating the habitat type concept at the *series* level. This figure has been very useful for introducing the habitat type classification concept, the relationship (or lack of) to forest cover types and the relative autecology (silvics) of tree species. The idea was later expanded to include under-growth vegetation, as shown in figure 3 (Pfister and others 1977). These illustrations are general models. One model for an entire study area would have numerous local exceptions. One solution is to develop several models --one for each major climatic region within the study area.

15. Regional Variation in Flora and Physical Factor Interactions Produce Different Kinds and Sequences of Habitat Types.--Regional variation is a problem that must be dealt with in classification of a large area and comparison of similar vegetation types of widespread distribution. One approach is formal definition of *regions* within the study area (Arno 1980). Illustrations like figure 3 can then be used to characterize patterns of species and type distribution within each region. Another approach is to utilize phase distinction to emphasize regional variants (Steele and others 1980; Mueggler and Stewart 1980). A third approach is to develop individual manuals for each region.

Distinguishing Between Critical and Non-critical Concepts.--Fifteen concepts have been listed. These are the ones most important to my understanding and teaching. I may have missed some that you believe are equally important. Each ecologist developing a classification for a new area usually provides additional insight and clarification of concepts; and, new concepts that lead to a better understanding of the intricacy of ecosystems will undoubtedly be documented as study continues. However, ecological concepts alone are not adequate to communicate the application of vegetation-based site classifications.

CLASSIFICATION CONCEPTS

Classification is defined as arranging objects into groups on the basis of their similarities or relationships. Many classification systems relate to the general subject of site and land classification, but need to be specified to compare and contrast and to make proper use of the classification systems. Three basic classification concepts or ideas are essential to application of habitat types in land management (Bailey and others 1978):

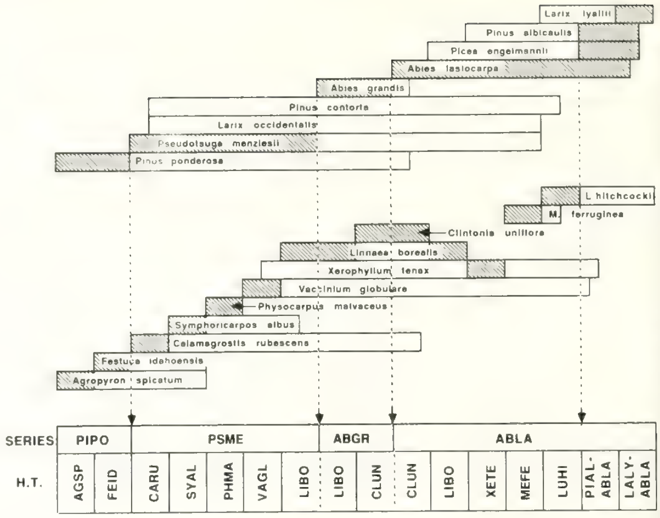

Figure 3--Relative amplitudes of key species and their role in defining habitat types. Illustration applies to vicinity of Missoula, Montana (from Pfister and others 1977).

1. Taxonomy is the Foundation for Application.--The taxonomy represents the formal classification and includes a list of types and a key to aid users.

2. Identification is the Application of the Taxonomy to the Land.--This is the process of placing (naming) a new individual according to the formal taxonomy. Two forms of identification are widely practiced:

a. Identification of points or individual stands, such as during inventory or stand examination, and
b. Mapping of taxonomic units as they are distributed on the landscape--with various scales and commensurate degrees of accuracy.

3. Regionalization is an Alternative Approach to Classification of Land Areas.--This approach is fundamentally a mapping process whereby homogeneous units of land are delineated, usually through a subdivisive process. Habitat type taxonomy may be used as descriptive (and rarely as diagnostic) criteria.

Recognition of the contrasting philosophy of site taxonomy and land mapping is helpful when communicating with other disciplines involved in land and resource classification. Although *land* classification is the title of this symposium, the habitat type system is primarily a *site* classification system, which may be used on its own or as a part of other land classification systems.

Habitat types are being used as an operational variable for soil taxonomy (cryic vs. frigid, etc.) and as an aid to mapping soils based on local observed correlations. Habitat types also are used as a descriptor and occasionally as a criterion for broader approaches (regionalization) when mapping landscapes to define areas of relative homogeneity for land use planning.

Habitat types were specified as a part of ECOCLASS (Corliss 1973) in the context of mapping and overlaying of maps to define *Ecological Land Units*. Associations were used as a part of the NATIONAL LAND CLASSIFICATION (Driscoll and others 1984), a component taxonomic system used to apply multiple taxonomies to a point or small unit of land--the dual name being termed an *Ecological Respone Unit*. The fact that ECOCLASS was a mixture of taxonomic and regionalization concepts and that the NATIONAL COMPONENT LAND CLASSIFICATION is primarily a taxonomic system illustrates that conceptual problems in the field of land classification are still not operationally resolved (at least not in the literature)!

APPLICATION CONCEPTS

Concepts for application or linking of site classifications to resource management have been evolving for some time and this symposium is the first formal effort to assess how far we have progressed. New ideas and concepts require time and understanding of value to be accepted and implemented.

Daubenmire published the first habitat type classification in 1952. Acceptance and use in forestry research and management during the 1960's led to commitment of research and management dollars to finance expansion and application in the 1970's. The steps or concepts involved in developing an operational system were and remain:

1. Decision About the Kind of System--Land management and research organizations need to decide what kind of ecological classification system is most appropriate (coordination of research and management on this decision is vital).

2. Planning, Finances, and Personnel--Someone must develop a plan, provide or find the financing, and obtain qualified personnel to complete the task.

3. Developing the Taxonomy--An effective vegetation-based site classification requires quality field sampling, appropriate analyses, ecological intuition, and documentation (Pfister and Arno 1980).

4. Training the Users and Application Specialists --Training is crucial and includes understanding of concepts, indicator species recognition, proper use of keys, mapping techniques, and proper interpretation of available management implications.

5. Developing Applications for Natural Resource Management--Applications require development of the relationships between the ecological classification and ecological knowledge relative to appropriate natural resource concerns. This can be done in several ways:

   a. By ecologists, from supplementary data and observations.
   b. By research specialists who stratify their data, analyze, and report results in relation to habitat types.
   c. By management specialists, summing up their own data, observations, and experience to develop their own local (usually informal and unpublished) guidelines.
   d. By teams of ecologists, resource scientists, and management specialists, pooling their combined knowledge and intuition for a synergistic, documented contribution to knowledge.
   e. By symposiums such as this one!

Each of the approaches has some problems. Many ecologists do not have a strong background in the natural resource areas where interpretations are needed. Many research specialists do not have enough ecological background to make full use of the classification. Management specialists may solve their current, local problems, but there is no mechanism to capture the knowledge for use in other areas.

Team efforts offer the most promise for solid, documented applications. However, team efforts require cooperation, coordination, commitment, and support of upper level management. If formal team efforts are not possible, it behooves professionals to find a way to work cooperatively with other professionals for specific areas of concern.

Symposiums are an effective way to provide a documented update on status of knowledge--this symposium goes a critical next step by addressing the question--"Where do we go from here?"

OTHER CONFLICTS AND RESOLUTION

I would be remiss if I did not mention some concepts that have received a great deal of attention. The ecologists developing the classifications have discussed these in greater detail. Suffice it to say that:

--Acceptance of a continuum philosophy does not preclude one from developing a useful and practical vegetation-based site classification.

--Continuum-based methodology, such as indirect ordination, can provide useful insights into species-site and type-site relationships.

--Direct ordination of species and communities against individual factors is a possible alternative analytical and application approach. However, it has not been as popular for resource application as types that the manager can see, identify, and map in the field.

--Direct ordination of habitat type distribution against elevation and aspect has proved to be a very useful aid to habitat type mapping.

--Numerous mathematical computer assisted analysis techniques are available to make the job of analysis easier if the ecologist maintains control of the classification process.

The foolproof automatic classification that fits the data, the landscape, and the intelligence of the ecologist who has field familiarity with the data is not yet available, although many have been fooled! Many continue to search for the ultimate in artificial intelligence--which should be considered as an aid to natural intelligence--not as a replacement for it.

CONCLUSION

My goal has been to deal with the abstract--the concepts and ideas basic to using vegetation for land classification purposes. I hope that it did not fit that definition of making it more abtruse or difficult to understand. Rather, I hope that the abstraction represents the following dictionary definition:

Abstract--*noun*--*American Heritage Dictionary* (Morris 1979):

1. A statement summarizing the important point of a text.
2. The concentrated essence of the larger whole.

If all that failed, then learn a few species and try it yourself--you will like it! Identify a point. Better yet, map a small area and find out how the classification fits the stand or landscape you are working with. Mapping is one of the most rewarding experiences of using habitat types. If you haven't mapped an area, even just 10 to 40 acres, you have really missed something. Use of the classification system in the field is one of the best ways to understand the concepts.

REFERENCES

Arno, S. F. 1980. Forest regions of Montana. Res. Pap. INT-218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 39 p.

Bailey, R. G.; Pfister, R. D.; Henderson, J. A. 1978. Nature of land and resource classification. Journal of Forestry. 76:650-655.

Corliss, J. C. 1974. ECOCLASS--a method for classifiying ecosystems. In: Foresters in land-use planning. Proc. 1973 Nat. Convention Society of American Foresters , Washington, DC: 264-271.

Crawford, R. C.; Johnson, F. D. 1985. Pacific yew dominance in tall forests, a classification dilemma. Canadian Journal of Botany. 63:592-602.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Daubenmire, R. 1966. Vegetation: identification of typal communities. Science. 151:291-298.

Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. New York: Harper and Row. 300 p.

Daubenmire, R. 1981. The scientific basis for a classification system in land-use allocation. In: Land-use allocation: Processes, people, politics, professionals. Proc. 1980 National Convention Society of American Foresters, Spokane, WA:159-162.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agricultural Experiment Station. 104 p.

Driscoll, R. S.; Merkle, D. L.; Radloff, D. L.; Snyder, J. S.; Hagihara, J. L. 1984. An ecological classification framework for the United States. Misc. Pub. No. 1439, Washington DC: U.S. Department of Agriculture, Forest Service. 56 p.

Morris, W. (editor). 1979. The American heritage dictionary of the English language. Boston: Houghton Mifflin. 1560 p.

Mueggler, W. F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Research Station. 154 p.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Pfister, R. D.; Arno, S. F.: 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26:52-70.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology. 16:284-307.

PRIMARY SUCCESSIONAL THEORIES

M. Hironaka

ABSTRACT: The polyclimax theory is not an alternative to the monoclimax theory. The polyclimax theory deals with primary successional communities in the present-day timeframe. The monoclimax theory projects primary succession into the future until all the primary communities under the influence of the same climate converge and terminate in a single community; the climatic climax. The monoclimax theory, the polyclimatic climax theory, and the no-endpoint theory of primary succession all deal with projection of primary succession beyond present time. With the no-endpoint theory, there is no terminal community because primary succession never ends. The monoclimax theory claims there is one--the climatic climax. The polyclimatic climax theory claims there are several terminal communities, because of terminal soil differences.

INTRODUCTION

Generally, one does not associate primary succession with habitat type (Daubenmire 1952) or range site (Dyksterhuis 1949) classification, but there is a close relationship. Because there are conflicting and inconsistent theories that pertain to primary succession, it is important that we understand how they differ.

Although there is much variability in what is included in a "homogeneous unit," the plant association (American interpretation--see Daubenmire 1968) is the basic unit of classification of climax vegetation. This unit is the basis for the habitat type. The habitat type is defined as the aggregate areal extent of a plant association that an area supports or is capable of again supporting (Daubenmire 1952). Although not stated in specific terms, the range site classification is also a land classification based on the plant association that is constrained by levels of productivity (Dyksterhuis 1949; Shiftlet 1973). The added constraint of productivity makes the range site a more homogeneous land unit in terms of uniformity in species abundance and soils than the habitat type. Both classifications are based on climax communities, which are the endpoint communities of secondary succession. The endpoint of secondary succession is primary succession. Thus, the communities that make up a plant association are communities of primary succession.

MONOCLIMAX AND POLYCLIMAX THEORIES

The monoclimax theory (Clements 1916; Oosting 1948) and the polyclimax theory (Daubenmire 1968; Mueller-Dombois and Ellenberg 1974) pertain to primary succession (fig. 1). Although some view the two concepts as mutually exclusive (Mueller-Dombois and Ellenberg 1974), they are not when interpreted in the light of habitat type and range site classification because a different timeframe is involved.

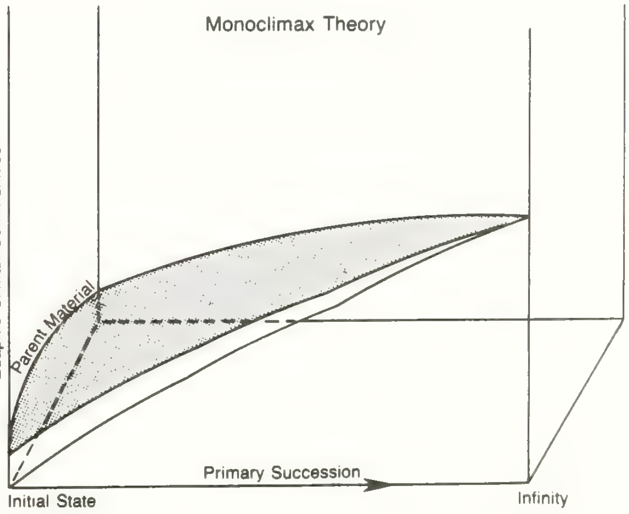

Figure 1--Author's conception of the monoclimax theory. Initial state is the beginning of primary succession on various parent materials. Climate is assumed to remain constant. All seres eventually converge onto a single climax community, the climatic climax.

Although the initial communities of primary succession are numerous and highly different, communities developing under the influence of the same climate eventually converge and become more similar as time passes. The monoclimax theory projects the timeframe of primary succession into the future until succession terminates in a single community; the climatic climax (Clements 1916). On the other hand, the polyclimax theory views

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M. Hironaka is Professor of Range Resources, University of Idaho, Moscow, ID.

primary succession through a narrower window of only a few decades and the communities present at the time of viewing are the climax communities that are classified into plant associations. The communities at the time of truncation are often referred to as edaphic, topographic, topo-edaphic, and climatic climaxes. These are the primary successional communities as they exist today, or as they would be if they were not recently disturbed.

The polyclimax theory deals in a different timeframe than the monoclimax theory (fig. 2). The polyclimax communities are primary successional communities of today and not in the distant future as envisioned in the monoclimax theory. It does not preclude the possibility of eventual convergence onto a single climatic climax when sufficient time lapses.

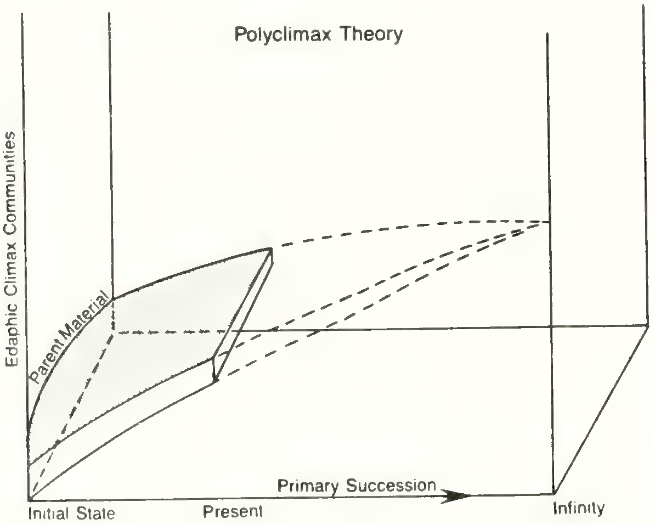

Figure 2--Author's conception of the polyclimax theory. Initial state is the same as for the monoclimax theory. Climate is constant. All seres are terminated as of present time.

If the endpoint of primary succession is thought to be polyclimatic--that is, having more than a single endpoint--the monoclimax and polyclimatic climax theories are conflicting theories (Mueller-Dombois and Ellenberg 1974). Interestingly, the polyclimatic climax theory is based on the premise that soil differences would be responsible for the different climatic climaxes. The use of the term "edaphic climax" for this situation is avoided because its use is already established in the polyclimax sense.

NO-ENDPOINT THEORY

About 10 years ago another primary succession theory was put forth (Pickett 1976). For lack of a name, I prefer to call it the no-endpoint theory (fig. 3). It views primary succession as never ending. Even under the hypothetical condition of constant climate, soil development will continue and the evolution of plants will go on and plant communities will undergo continuous change. The no-endpoint theory, in my opinion, overcomes the conceptual difficulties inherent in the other theories. It incorporates the dynamic theories of soil development (Jenny 1941; Jenny 1958), soil-vegetation relation (Major 1951) and plant evolution (Stebbins 1974). It has a lot of merit.

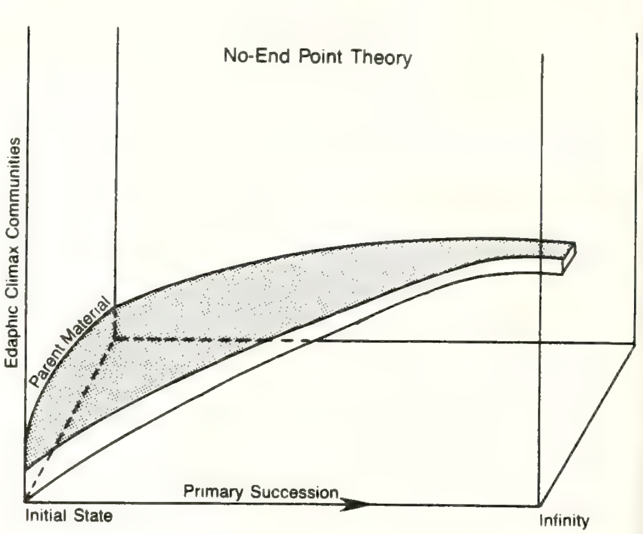

Figure 3--Author's conception of the no-endpoint theory. Initial state is the same as for the monoclimax and polyclimax theories. Climate is constant. Convergence is incomplete and seres do not ever fully converge. Vegetation change continues over time because of plant evolution and soil development.

Acceptance of the no-endpoint theory does away with the confusion associated with the term "climax community." Since primary succession has no endpoint, the term can be only associated with the endpoint of secondary succession. It would still retain its meaning of being the culmination of succession, the endpoint of secondary succession. The term would be universally meaningful, including its usage in context with polyclimax, plant association, habitat type, and range site concepts.

DISCRETE COMMUNITIES VERSUS CONTINUUM

Although it is not often stated, the discrete community versus the continuum controversy is restricted to plant communities (McIntosh 1958; Daubenmire 1966) of primary succession and not communities of secondary succession. The no-endpoint theory reduces confusion by restricting the definition of climax as the endpoint of secondary succession. The endpoint of secondary succession is primary succession. This makes each and every primary successional community a climax community.

For the discrete community concept to be an ecological truth, one is required to accept the idea that contiguous, temporal primary successional communities are abrupt and discrete, even though the successional process, environmental gradients, and time are continuous. This concept is difficult to accept because soil development is continuous, temporally and spatially (Jenny 1941, 1958), and to expect the plant community to remain virtually unchanged in its entirety for a span of time and then abruptly change into another community is difficult to envision. In addition, plant species tend to become more different through natural selection rather than more similar. This would result in plant communities becoming more heterogeneous and continuous than discrete over time (Whittaker 1975).

REFERENCES

Clements, F. E. 1916. Plant succession, an analysis of the development of vegetation. Carnegie Institute Washington Publication 242. 512 p.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Daubenmire, R. 1966. Vegetation: identification of typal communities. Science. 151:291-298.

Daubenmire, R. 1968. Plant communities--a textbook of plant synecology. New York, NY: Harper and Row. 300 p.

Dyksterhuis, E. J. 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management. 2:104-115.

Jenny, H. 1941. Factors of soil formation. New York, NY: McGraw-Hill Book Co. 281 p.

Jenny, H. 1958. Role of the plant factor in pedogenic functions. Ecology. 39:5-16.

Major, J. 1951. A functional, factorial approach to plant ecology. Ecology. 32:392-412.

McIntosh, R. P. 1958. Plant communities. Science. 3316:115-120.

Mueller-Dombois, D.; Ellenberg H. 1974. Aims and methods of vegetation ecology. New York, NY: John Wiley and Sons. 547 p.

Oosting, H. J. 1956. The study of plant communities--an introduction to plant ecology. 2nd edition. San Francisco, CA: W. H. Freeman and Company. 440 p.

Pickett, S. T. A. 1976. Succession: an evolutionary interpretation. American Naturalist. 110:107-119.

Shiftlet, T. N. 1973. Range sites and soils in the United States. In: Hyder, D. N., ed. Arid shrublands-proceedings of the third workshop of the United States/Australia rangelands panel, Tucson, AZ, March 26-April 5, 1973. Denver, CO: Society for Range Management. 26-32.

Stebbins, G. L. 1974. Flowering plants--evolution above the species level. Cambridge, MA: Belknap Press. 399 p.

Whittaker, R. H. 1975. Communities and ecosystems. 2nd edition. New York: MacMillan Publishing Co., Inc. 385 p.

CONSERVATION OF NATURAL DIVERSITY:

THE ROLE OF AN ECOLOGICAL CLASSIFICATION

Patrick S. Bourgeron

ABSTRACT: A goal of The Nature Conservancy is the global preservation of natural diversity. Steps to advance this goal are defined. The Nature Conservancy's efforts towards the regional correlations of local classifications in the western U.S. are presented. A second product of the regional classification will be the improved understanding of diversity patterns, understanding useful in preserve selection and management.

INTRODUCTION

The objectives of an ecological classification must be clearly stated. The tool must match the stated objectives. The purpose of this paper is to summarize The Nature Conservancy's approach to ecological classification that is used in the western U.S. and the potential use of the classification to preserve natural diversity.

GOALS OF THE WESTERN REGIONAL ECOLOGY EFFORT

The Nature Conservancy's mission is the global preservation of natural diversity. As part of a National Task Force, the western regional ecology effort has, among others, two stated objectives:

(1) To develop an internally consistent ecological classification for the western portion of The Nature Conservancy's global system.

(2) To apply the above system to the selection and management of ecological systems for conservation in a regional/continental perspective.

NEED FOR CLASSIFICATION

It is appropriate to ask: (1) why do we need a classification for conservation of natural diversity? (what are the relationships between natural diversity and classification?); (2) why a regional approach? (what are the implications of a regional approach to the conservation of natural diversity?)

Natural (or biological) diversity is generally defined as the diversity of life forms (such as species), their genetic diversity and the ecological functions and processes they perform (Wilcox 1984). Natural diversity is also conveniently organized at different levels (table 1). At each level, the fundamental unit is an element. This definition of natural diversity identifies entities that serve as focal points for conservation, research, and management.

The Nature Conservancy uses a "coarse filter/fine filter" approach to preserving natural diversity (Jenkins 1976). A primary objective is to protect examples of each of the communities (the coarse filter) found in an area. In this way, 85-90 percent of the natural diversity found in the area will be preserved (Jenkins 1976, 1982). In addition, preserving high-quality examples of communities is of importance in itself since these examples demonstrate ecological processes and serve as experimental controls against which other management strategies can be compared (Jenkins 1982). Rare and endangered species are most likely to fall through the cracks of the "coarse filter" (Jenkins 1976). The "fine filter" is aimed at these species that are dealt with on an individual species basis (The Nature Conservancy's Heritage operations manual 1987; see discussion in Jenkins 1976, 1982).

An ecological classification must therefore (1) identify all communities (to preserve the full array of communities), and (2) define the range of each community (to preserve the full array of natural diversity found over the range of each community). When these two criteria are met, this classification provides a good basis for preserving the full array of elements that compose natural diversity over any area. A regional/continental approach to community classification is necessary to identify all communities and define the range of each one. The definition of an optimal strategy for preserving the full array of natural diversity clearly demands a regional/continental approach.

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Patrick S. Bourgeron, Regional Ecologist, Rocky Mountain Heritage Task Force, The Nature Conservancy, Lakewood, CO.

In summary, the community concept is central to the global preservation of natural diversity. Landscapes need to be divided into communities that are units that occur repeatedly in time and space. The community is used as a "coarse filter" to preserve groups of species in relatively homogeneous habitats over the landscape. A regional classification is used to generalize knowledge about a few samples located in the region to as many stands in the whole area as possible. The "coarse filter" thus defined enhances our efforts to preserve natural diversity with economy.

Table 1--Organization of natural diversity at different levels. Adapted from Wilcox (1984)

Level of Organization	Component	Element (Example)
Molecular	Genes	Genes for salinity tolerance and resistance to verticillium wilt in the strawberry *Fragaria chiloensis*
Populational	Populations	Deer herd in George Reserve
Species	Species	Grizzly bear (*Ursus arctos*)
Ecosystem	Community	*Abies lasiocarpa/Vaccinium caespitosum*

A STRATEGY

During the process of building a regional classification and using it as the "coarse filter" for the global preservation of natural diversity, the following questions need to be addressed:

(1) What are the local communities found in a landscape? (This is the classification proper.)

(2) What is the range of distribution of the above communities? (These are the regional correlations of local classifications leading to the regional/continental classification.)

(3) What are the relationships of communities to one another, and to the environment, both locally and regionally? (This is the ecological interpretation that gives the classification its predictive power.)

(4) Is there a relationship between local community diversity and other levels of diversity? (This is the search for the respective role of local and regional processes and historical events in generating and maintaining local community diversity.)

(5) To what extent will reduction and alteration of habitats modify patterns of diversity in local communities and over the range of distribution of a given type? (This is the search for an optimal regional/continental protection strategy.)

To answer these questions requires an ecological classification that is internally consistent and that is based on sound ecological principles (Pfister 1986). In the western U.S., The Nature Conservancy uses the plant association concept (Braun-Blanquet 1921, 1964; Daubenmire 1952, 1968, 1970; Daubenmire and Daubenmire 1968; Flahault and Schroter 1910; Pfister and Arno 1980). This approach ensures that the criteria of consistency and ecological soundness are satisfied. It also allows The Nature Conservancy to make use of the large array of data that is available today over the western U.S. The Nature Conservancy's system includes communities that are compositionally and structurally maintained by recurrent natural disturbances, such as fires and grazing by large native ungulates. In the habitat typing system, the term plant association is restricted to climax or potential natural vegetation types (Daubenmire 1968; Pfister and others 1977). In agreement with the original definition of a plant association (Flahault and Schroter 1910), the subclimax and seral communities are recognized using the same criteria as the climax types, but they are called community types to keep The Nature Conservancy's system compatible with the widely used habitat typing terminology.

AN EXAMPLE OF THE REGIONAL APPROACH

To illustrate the steps involved in answering the first three questions, we will take the example of the spruce-fir forests with *Vaccinium* in the understory and related types. Twenty-five types falling in this complex were found in 32 publications. Their acronyms are:

ABLA/CABI
ABLA/LIBO
ABLA/LUHI
ABLA/RUPA
ABLA/SETR
ABLA/STAM
ABLA/VACA
ABLA/VAGL
ABLA/VAME
ABLA/VAMY
ABLA/VASC
ABLA-VASC/LIBO
ABLA-PIEN/VASC
ABLA-PIEN/VASC
PIEN-ABLA/PAMY
PIEN-ABLA/VACA
PIEN-ABLA/VASC
PIEN/CALE
PIEN/LIBO
PIEN/VACA
PIEN/VAMY
PIEN/VAMY-POPU
PIEN/VASC
PIEN/VASC-PODE
PIEN-RIMO-PODE-BROM

Each publication provides a local answer to questions 1 and 3. However, without the regional correlations of these types, we do not know how similar or dissimilar they are. Names alone are of little value at the regional scale, as authors may have different naming conventions, and ecological similarities or dissimilarities are not necessarily apparent from the name. The regional correlations of local types are the means of answering the following questions (Johnston 1983): Are types with identical names the same? Are types with different names separate entities? Is a phase in a local classification a true phase of a type or the expression of a related but distinct type at the limit of its range? How do finalized regional types relate to one another and to the environment?

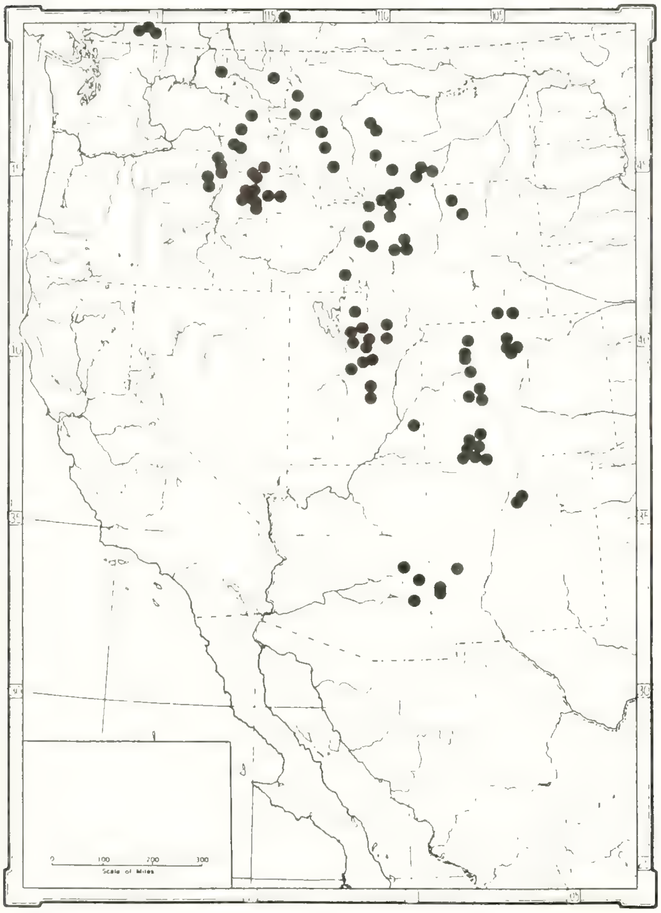

Figure 1--Map of the areas where the study spruce-fir types were sampled.

The regional correlations of the types are based on the summary tables. Work focuses on how local types relate to each other, and whether they should be lumped under the same name. To use published data sets, two criteria had to be met: (1) concepts and methodology used to define the types had to be similar and (2) data had to be expressed in percent cover (most of the publications used this or a cover class) or in a unit easily converted to percent cover. All but 3 of the 32 publications described "habitat typing" classification.

Ninety-six summary tables, including phases when available, were retrieved. The represented areas ranged from Canada to southern Arizona and New Mexico (fig. 1). Data were lumped at the species level. Nomenclature follows Kartesz and Kartesz (1985). Total number of species and the breakdown by life form are:

Total number of species = 491

Trees = 22
Shrubs = 74
Graminoids = 80
Forbs = 307
Others = 8

On-going analyses include clustering, ordination and analysis of variance. The dendrogram (fig. 2) was obtained with Ward's method variable transformation (Orloci 1967), a polythetic agglomerative technique available through CLUSTAN (Wishart 1978), using squared Euclidian distance (Orloci 1978) on unstandardized data. To fit CLUSTAN's dimension requirements, the data set was reduced to include only the 189 species with cover greater than 3 percent.

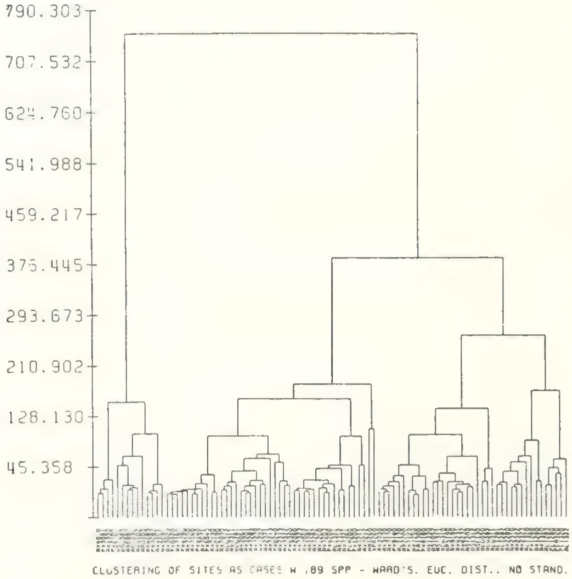

Figure 2--Cluster dendogram of the summary tables using Ward's method.

Five groups are identified in figure 2. The first break separates types found in Arizona, southern Colorado and New Mexico (group 1) from types found north of southern Colorado Gunnison National Forest (groups 2, 3, 4 and 5), but for two exceptions. These are a southern Arizona type and a central Idaho type that are associated with group 4 and 1 respectively. Group 4 and 5 appear to separate the cool and drier Abies lasiocarpa and closely related types (group 5) from the cool but moister (or less summer drought constrained) Abies lasiocarpa and closely related types (group 4). Group 3 appears to include types on sites dominated by cold air drainage or accumulation. Group 2 includes all other types.

These results are preliminary and are shown only to illustrate the complexity to be encountered in correlation efforts, including the complexity of possible relationships among types. Enthusiasm for cursory geographical and environmental interpretation of the clusters is tempered by (1) the indication of possible misclassification due to the technique and (2) the fact that phases of the same types are sometimes found in various groups. Further work will include: analysis of the species groups leading to the clusters, the sensitivity of the results to various species reduction and transformation strategies, the use of other techniques, structural and diversity analysis, ordination, and other approaches to clarify the ecology of the associations.

USE OF CLASSIFICATION FOR DIVERSITY PATTERN ANALYSIS

The regional/continental classification will permit the determination of species diversity patterns within small areas (stands) of matched, similar and homogeneous habitat within regions. Using the "coarse filter" approach, most of the natural diversity can be protected over time. However, long term protection requires understanding of the processes that generate and maintain diversity in local communities. Ecologists are beginning to realize that local community diversity reflects the influence of global processes, such as dispersal, species production and unique and historical circumstances, as well as local factors, such as competition, predation and grazing (Ricklefs 1987). Determining the relative role of local and regional processes that generate and maintain natural diversity is central to its long-term maintenance.

If local conditions determine local community diversity, variation in diversity at higher levels should have little influence on local community diversity (Cornell 1985a,b; Ricklefs 1987; Terborgh and Faaborg 1985). This interest in diversity at different levels relates directly to question 4: Is there a relation between local community diversity and other levels of diversity? The regional approach to classification provides the data to test the relation between different levels of diversity in habitats that are considered to be either the same or similar.

As an example of such a use of the ecological classification, the number of shrub species found on the average in a stand of a given plant association (of the spruce-fir complex) is plotted against the total number of species that can be found in the same plant association over a large surrounding area such as a national forest (fig. 3). The significant correlations between the two levels indicate that shrub diversity depends on the overall number of shrub species that can survive that kind of environment. Therefore the number of shrub species found on the average on a given site is sensitive to processes such as geographic dispersal and historical accumulation of shrub species that can be found in the given type of habitat over a given area. To this extent, any reduction in the number of shrub species that can be found in the types considered over the area will initiate a decline in local shrub diversity in the same types, from which there is no recovery. This result implies that preservation of the maximum number of shrub species that can survive in the given environment over the area considered is necessary to preserve shrub diversity in any occurrence of the types considered. At present, we are doing the same analysis at other levels of ecological organization.

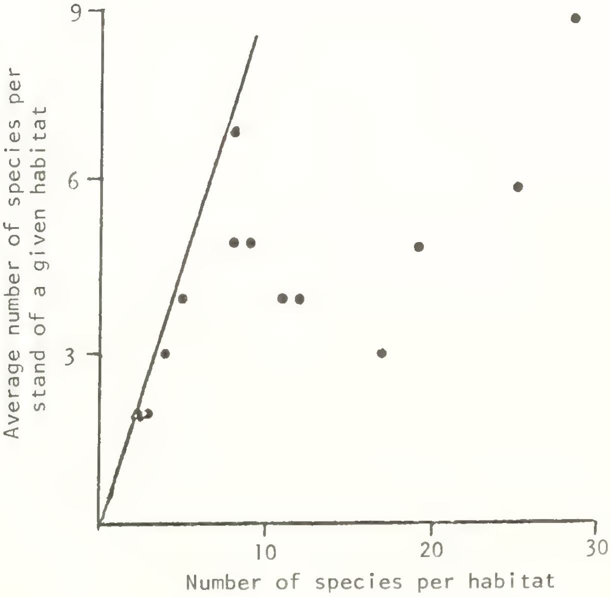

Figure 3--Relationship between the average number of shrub species at one site and the total number of shrub species found in the same habitat over a large area.

CONCLUSIONS

To achieve our goal of conserving natural diversity, we must have a sound ecological classification as a tool. This classification needs to be standardized to compare patterns over landscapes, over whole regions, or even over whole continents. Local classifications must be correlated regionally and/or at the continental scale. The use of a standardized classification system over large areas permits the kind of regional correlations that The Nature Conservancy is doing at present in the western U.S. The final product will be a regional classification.

With such regional/continental classifications, ecosystem patterns, structure and dynamics, and diversity patterns can be studied at all the proper spatial and temporal scales that influence the characteristics of ecosystems. Optimal strategies for the global preservation of natural diversity (Jenkins 1976, 1982) based on the "coarse filter" approach can then be defined.

The Nature Conservancy's efforts toward the global preservation of natural diversity include the following steps, that are part of its long-established Natural Heritage programs (see Jenkins 1982), and its preserve selection and design and stewardship efforts:

(1) A regional classification of all ecological systems.

(2) A basic model of diversity patterns in all ecosystems.

(3) Detailed models of relations of diversity patterns at different levels of ecological organization.

(4) An integrated management system of the above information.

(5) Guidelines on conserving and managing units of the classification.

REFERENCES

Braun-Blanquet, Josias. 1921. Prinzipien einer systematik der pflanzengesellsdraften auf floristischer grundlage. Jahrb. St. Gall. Nat. Ges. 57: 305-351.

Braun-Blanquet, Josias. 1964. Pflanzensoziologie, grundzuge der vegetationskunde. 3rd ed. New York: Springer. 865 p.

Cornell, Howard V. 1985a. Local and regional richness of cynipid gall wasps on California oaks. Ecology. 66 (4): 1247-1260.

Cornell, Howard V. 1985b. Species assemblages of cynipid gall are not saturated. American Naturalist. 126 (4): 565-569.

Daubenmire, R.F. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts on vegetation classification. Ecological Monographs. 22 (4): 301-330.

Daubenmire, R.F. 1968. Plant communities. New York: Harper-Row. 300 p.

Daubenmire, R.F. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington State University, Washington Agricultural Experiment Station, College of Agriculture. 131 p.

Daubenmire, R.F.; Daubenmire, Jean B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, Washington Agricultural Experiment Station, College of Agriculture. 104 p.

Flahault, C.H.; Schroter, C. 1910. Rapport sur la nomenclature phytogeographique. In: Actes III: Congres international de botanique; 1910; Bruxelles, Belgium: Societe Internationale de Botanique: 1: 131-164.

Jenkins, Robert E., Jr. 1976. Maintenance of natural diversity: approach and recommendations. In: Transactions of the 41st North American wildlife conference; 1976, 1976 March 24; Washington, DC; Washington, DC: Wildlife Management Institute: 441-451.

Jenkins, Robert E., Jr. 1982. Planning and developing Natural Heritage protection programs. Unpublished paper prepared for the Indo-U.S. workshop on biosphere reserves and conservation of biological diversity; 1982 March 1-14; Bangalore, Karnataka State, India. On file at: The Nature Conservancy, Science Program, Arlington, VA. 17 p.

Johnston, Barry C. 1983. Regional correlations among vegetation classification studies. In: Moir, William H.; Hendzel, Leonard, technical coords. Proceedings of the workshop on southwestern habitat types; 1983 April 6-8; Albuquerque, NM; Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 96-101.

Kartesz, John T.; Kartesz, Rosemary. 1985. A synonymized checklist of the vascular flora of the United States, Canada, and Greenland. Unpublished Revision of the 1980. On file at: The Nature Conservancy, Science Program, Arlington, VA. 694 p.

Orloci, Lazlo. 1967. An agglomerative method for classification of plant communities. Journal of Ecology. 55. 193-206.

Orloci, Lazlo. 1978. Multivariate analysis in vegetation. The Hague, The Netherlands: Junk. 276 p.

Pfister, Robert D. 1986. Development of a vegetation-based approach to site classification. In: Clamby, Gary K.; Pemble, Richards H., editors. Proceedings, 9th North American prairie conference: prairie: past, present and future; 1984 July 29-August 1; Moorhead, MN; Fargo, ND: Try College, University Center for Environmental Studies: 74-76.

Pfister, Robert D.; Arno, Stephen F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26 (1): 52-70.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Ricklefs, Robert E. 1987. Community diversity: relative role of local and regional processes. Science. 235: 167-171.

Terborgh, John W.; Faaborg, John. 1980. Saturation of bird communities in the West Indies. American Naturalist. 116 (92): 178-195.

The Nature Conservancy, Science Program. c1987. Heritage operations manual. Arlington, VA: The Nature Conservancy, Science Program.

Wilcox, Bruce A. 1984. Concepts in population biology: applications to the management of biological diversity. In: Cooley, James L.; Cooley, June H., eds. Natural diversity in forest ecosystems: Proceedings of the workshop; 1982 November 29-December 1; Athens, GA; Athens, GA: University of Georgia, Institute of Ecology: 155-172.

Wishart, D. 1978. CLUSTAN, User Manual 3rd Edition. Inter-University/Research Councils Series Report No. 47. Edinburg, Scotland: University of Edinburg.

EDUCATION AND TRAINING FOR PERSONNEL WORKING WITH VEGETATION-BASED LAND CLASSIFICATIONS

Frederic D. Johnson

ABSTRACT: Results of a poll sent to 80 forest agency silviculturists in the far-western United States indicate a lack of confidence in the accuracy of field crews who are applying vegetation-based land classifications. Almost three-fourths of respondents believe training is inadequate. Most data generated by field crews goes into a permanent data base. New professionals and superiors are judged weak in appreciation of the complexities of such classifications. Longer and better training programs are an indicated need. A poll of 9 of 11 far-western accredited forestry schools reveals that undergraduate forestry students apparently need more time in field practice of vegetation classification, more exposure to concepts critical to understanding these classifications, and better understanding of plant identification.

INTRODUCTION

When asked to present a paper on the education and training of practitioners of the exotic art of classifying land by plant communities, I accepted readily. I've been teaching field habitat typing since 1956—to undergraduates in field ecology at summer camp for over 25 years, to graduate students in a fall course for over 20 years, and to practicing professionals in 15 week-long short courses taught over the past 10 years. Although I definitely had some ideas on the subject, I soon realized that my experience would translate to anecdotal material. I had no real data.

I had plenty of horror stories—especially from graduate students and professionals, many who volunteered "I've been doing this all wrong"—"for all last summer", or "a couple of years", or "for several years". Stories of misidentification—such as the crew that mistook *Erythronium grandiflorum* for *Clintonia uniflora*—which in these parts is about equivalent to calling a Douglas-fir a whitebark pine. The whole summer's work for that crew had to be repeated the next season. I heard of a crew working in clearcuts who identified *Ribes viscosissimum* as *Physocarpus malvaceus*, and thus, since Douglas-fir had been planted, typed a western hemlock habitat as *Pseudotsuga/Physocarpus*. Just a couple of months ago a non-forestry graduate student on a 3-man field crew came in and indicated he felt that their habitat typing was not being done properly (he put it more succinctly!). As I questioned him it was soon evident he was right. Then he asked another question. "How do you tell grand fir from subalpine fir?" "You mean your crew-boss can't help you?", I asked. "No, he asked me to find out." I hear repeatedly of field crews standing midst a brush field, or in a newly burned clearcut trying to determine forest habitat type. Anyhow, lots of feedback over the years.

But no *real* data! So I sent out 91 questionnaires. One set of questions went to each of the 11 accredited forestry schools in the far west—(NAU, UA, UC-B, HSU, CSU, UI, UM, OSU, USU, WSU, and UW). A different questionnaire was sent to 80 district silviculturists for USDA Forest Service, Bureau of Land Management, and Idaho Department of Lands. Locations were determined on a semi-random selection from directories. There was a slightly heavier weighting to Idaho and Montana since they have been using forest habitat typing for the longest period. Agencies in California were not polled, since their classification is just beginning to be used. But, agencies in all ten of the remaining far-western states were polled.

AGENCY QUESTIONNAIRE

Of the 80 sent to silviculturists, 71 (89%) were returned. (Could the high return rate indicate high interest?) Of those returned, 83 percent (59/80) had a forest habitat type or forest association classification for their area. For the 17 percent that had no classification available, 60 percent expected one in under 2 years.

Asked to evaluate the local forest habitat or plant association classification: 80 percent checked "very useful", while only 5 percent checked "of little value". Another 5 percent indicated that local manuals had erroneous information or that there was a need for updating the manual or that there were poor or misleading keys.

> Comments: "The best working tool for foresters I've used in 25 years".
> "Would be better if more professionals understood it ".
> "Needs better management implications".
> "Lacks usable keys".
> "Needs better pictures".

After this general question, there were three parts, one for non-professional and seasonal personnel, one for contractors and one for professionals.

Non-professional and Seasonal Personnel

Two-thirds (39/59) of the professional silviculturists replying would like to screen applicants for seasonal work for prior experience or training in forest habitat type or association work. Less than half (28/59) indicated that this was possible. One respondent presented an interesting contrast: **"Could applicants be screened?"** — "YES." **"Do you prefer to screen them?"** — "NO".

> Comments: "We'd like to screen applicants but haven't had that luxury yet."
> "Hiring practices won't allow screening."
> "We can do limited screening only if we have sufficient applicants."

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Frederic D. Johnson is Professor of Forest Ecology, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID.

Training is a matter of considerable interest and the results of the related series of questions was variable. The question asked: **How much field training do new personnel for which you are responsible receive before using the classification?** The results:

Response	Percent/Number	
No training at all	12%	(7/59)
3 - 8 hours	47%	(28/59)
12 - 16 hours	8%	(5/59)
40 hours (5 days)	10%	(6/59)
Indefinite or variable	15%	(9/59)
Blank	7%	(4/59)

From these data, three-fifths of non-professional and seasonal personnel receive one day or less of training in identification of forest habitat types or associations.

Whatever the training period, 71 percent (42/59) indicated that data taken by seasonals or non-professionals went into a permanent data base! I went back through the questionnaires to develop this interesting point: of the 59 percent of seasonals or non-professionals with from 0 to 8 hours training in vegetation classification, 91% indicated the data went to a permanent data base. It seems the less the training, the more likely was the data to get to a permanent data base!

The responses to the question, **Who conducts the training?**, were so variable that they were difficult to group. Seasonals with experience (10%) were involved in training other seasonals. Crew supervisors were involved in 15 percent of the training, but crew bosses are often seasonals. ''Experts'', such as zone ecologists, authors of classification manuals, instructors in university shortcourses or ecologists on contract accounted for 15 percent of training programs. Many answers (29%) were of dubious value with answers like ''USFS'' or ''BLM'' personnel. The remainder were too variable to classify.

Are the training programs (for seasonals and non-professionals) adequate? No: 72 percent (41/57), Yes: 28 percent (14/57), blank—2 responses.

How can training programs be improved? ''More time with experts,'' was the reply for almost half (46% - 27/59). This figure combines a variety of replies, such as: ''More time with zone ecologist'', ''several days to a week with experts'', ''take university shortcourse'', ''everyone should spend a week with outside experts'', '' . . . would like to send more workers to the 40-hour course''. More time for training was the reply by 20% (12/59). By contrast, one remark: ''Three hours of training produces an adequate job.'' Some indicated better preparation by instructors (15% - 9/59).

Suggestions for improvement brought some interesting comments. Several indicated that their professional personnel needed more preparation in college, stressing concepts, classification systems and plant identification. And, along this line, another group (24%) indicated a need for better understanding of concepts and ''theories'' on which vegetation-based classifications are founded.

A pertinent general comment fits well here: ''My superiors have no idea what a habitat type is, how hard they are to determine, or how to apply them!'' From my experience in conducting professional-level habitat type short courses; it is very rare that upper eschelon administrators attend, and if they do, it's for a few hours of field work during a week long course. Perhaps this is part of the problem with inaccurate data reaching permanent data banks.

Contractors

Another section of the agency questionnaire dealt with contractors. The lead question was **Are contractors who are required to provide association/habitat type/community type judgments adequately trained and qualified for classification work?** The answers: No: 44 percent (26/59), Yes: 19 percent (11/59), possibly or maybe: 2 percent (7/59), unintelligible or blank: 25 percent. There were only a few comments from those who did not reply; however, three respondents indicated that they don't have contractors do vegetation classification due to lack of training.

Who Trains Contractors? If I have interpreted a variety of responses correctly, then contractors train themselves. Only 3 of 59 respondents indicated they trained contractors. There was a general tone from comments that contractor work on vegetation typing is suspect. Which brings us to a final statistic on the apparently self-trained, ill-prepared contractors: of the vegetation classification work they do, 48 percent goes into a permanent data base!

Professional Personnel

The third part of the agency questionnaire related to new B.S. or M.S. foresters. These data are from 56 respondents.

How much field training do new professionals . . . receive before using the classification? The results:

No formal training at all - 11 percent (6/56). Comments: ''Must pick it up on the job,'' or, ''expected to have it in college.''

Response	Percent/Number	
None	11%	(6/56)
4 - 8 hours	38%	(21/56)
2 days	9%	(5/56)
4 - 5 days	34%	(19/56)
variable	9%	(5/56)

I asked for some judgments on new professionals and the response level dropped to 45 of the 56 that answered part of this section. I asked respondents to indicate what qualifications they expected of new professionals and then to provide a judgment of their college preparation:

- Concepts of plant community ecology:
    expected to have had in college - 100%
    preparation:
        good or adequate - 53% (24/45)
        inadequate or apparently absent - 47% (21/45)
- Concepts of land classification using vegetation:
    expected to have had in college - 93% (42/45)
    preparation:
        good or adequate - 38% (17/45)
        inadequate or apparently absent - 62% (28/45)
- Course work leading to reliable field identification of plants:
    expected to have had in college - 89% (40/45)
    ability in plant identification:
        good or adequate - 44% (20/45)
        inadequate or apparently absent - 56% (25/45)
- Practice in college in field identification of forest communities:
    expected to have had in college - 89% (40/45)
    ability in field identification and classification of communities:
        good or adequate - 44% (20/45)
        inadequate or apparently missing - 56% (25/45)

District silviculturists indicate that the majority of new professionals lack the knowledge needed to apply or use vegetation-based land classifications. Yet, almost 50 percent of new professionals receive 2 days or less of training once on the job.

> Comments: ''We haven't had a new forester for so long, I can't answer'', ''depends on whether they're from the east or west - easterners aren't as well prepared.''

UNIVERSITY QUESTIONNAIRE

A different questionnaire was addressed to the professor of forest ecology at the 11 accredited forestry schools in the far west. Answers all related to required work in forest management/forest resources (and similar) major programs at the B.S. level. Responses were received from nine schools; most replies were from professors of silviculture.

Fifty-six percent felt students need more course work on the concepts of community ecology. Asked how many hours of class time is devoted to the explanation/discussion of forest communities at the association level, the results were quite variable—from 3 to 40 hours. Those with high figures probably included field practice sessions at summer camp.

All nine schools required some time devoted to guided field work in the identification of forest communities. The average was 21 hours (about 3 field days—figuring 7 hours of class and 1 hour of travel in a class day). However, the range was great—from 6 hours to 5 days. Sixty-seven percent of the professors responding felt their students need more time on field identification of forest communities. Sixty-seven percent also felt that students needed more class time on land classification systems.

Forty-four percent felt students need more basic plant taxonomy. Yet, only three schools of the nine responding require a course in taxonomic or systematic botany. Forestry students must pick up their plant taxonomy in courses such as dendrology, range, general botany, resource ecology or at summer camp. It's not surprising that 56 percent felt their students need more time devoted to field identification of plants.

Do you feel your students are adequately prepared to put forest association/habitat type/community type classifications to use in the forestry profession? No—78% (7/9)!

The nine ecology and silviculture professors who responded were unanimously in agreement on the question: **Do you feel such classifications have a valid place in forest management practices?** All answered "yes."

Should forest agencies be charged with teaching the following aspects of land classification by vegetation (to professionals)?

Concepts of plant community ecology	- No 6/9, Yes 2/9, Blank 1/9
Concepts of land classificaton systems	- No 8/9, Yes 1/9
Plant identification	- No 6/9, Yes 2/9, Blank 1/9
Field practice in identifying communities	- No 2/9, Yes 7/9

As a parting gesture, I chose 17 terms from the glossaries of current association or habitat type field manuals. I asked respondents to **Check the terms listed below that graduating B.S. students would be expected to define and properly apply.** Here are the terms and the positive answers from nine forestry school respondents:

accidental (species)	3
(plant) association	8
canopy coverage	9
climax	9
constancy	1
disclimax	5
ecotone	9
edaphic climax	8
fidelity	1
forb	9
graminoid	9
habitat type	9
indicator (plant species)	8
riparian	8
seral	8
succession	9
union (of plants)	1

From this we can assume that most undergraduate foresters should understand 75% of these terms. However, note that most forest habitat type and association field manuals include in the appendices plant lists per unit and include cover and constancy values - yet only one forestry school respondent checked "constancy" as a term forestry graduates were capable of defining and applying. And only one indicated that the term "fidelity" was known to students, yet fidelity is a very important aspect of community definition and of the theory of plant indicators.

SUMMARY AND RECOMMENDATIONS

The results of this survey indicate that silvicultural personnel, both from management agencies and contractors, need better and longer training courses that take 4 or 5 days in local field situations. It appears that a course designed for the specific needs of land management administrators should be developed. Attendance at such courses by forestry professors utilizing this system of land classification merits consideration.

Increased awareness by all personnel of the conceptual basis for habitat classification is needed. Training programs should stress misuse as well as proper use. Care must be taken to assure that only accurate information from the field is used in permanent data bases. Data from personnel who are untrained, self-trained or inadequately trained should not be considered.

Forestry schools can assist by providing the profession with graduates who are better equipped to understand and apply vegetation-based land classifications. In particular, many forestry students need more time devoted to supervised field identification of communities and a broader view of vegetation-based classifications as applied by an increasing number of management agencies throughout the western United States.

Both agency personnel and forestry students would benefit from better knowledge of the interaction of soils, topography and vegetation.

This survey pertained to western agency personnel in silviculture and forestry students. Yet there seems no reason to believe that other disciplines working with vegetation-based land classifications don't have problems similar to those explained. More than likely the recommendations outlined would be beneficial to all land management personnel using this system.

PLANT COMMUNITY CLASSIFICATION: FROM CONCEPT TO APPLICATION

Frederick C. Hall

ABSTRACT: Concepts for classifying plant communities by potential natural vegetation are well established (the plant association). A primary purpose for developing a plant association classification is to store and retrieve information on plant communities useful for land management. Associations may be classified according to potential species dominance, productivity, reaction to management and identifiability when disturbed. The classification is one of six kinds of information needed for land management: others are current vegetation, topography, soil, current use, and tract location. Applications to wildlife habitat management, livestock forage rating requirements, and tree production and regeneration are discussed.

INTRODUCTION

Ecosystems are composed of biotic and abiotic elements. The vegetative component, plant communities, are usually classified into potential plant associations (habitat types) based on: (1) potential vegetation, (2) productivity characteristics, (3) management considerations, and (4) identifiability in the field despite disturbance. Associations may be used to characterize livestock forage ratings, revegetation opportunities, reforestation characteristics, growth potentials for wood, shrub and herb production, and reaction of the plant community to management. When associations are identified in vegetation resource inventories, a system for storage and retrieval of information on management and ecosystem response is provided.

This paper describes an approach used by the ecology program of the USDA Forest Service in the Pacific Northwest Region for the past 25 years. The program is composed of 15 field ecologists with a three-person administrative group headquartered in the Regional Office.

Previous papers in this symposium have discussed the theory, concepts, and methods of plant community classification. This paper introduces a few applications of the concepts and theories. The term "association" will be used for a unit of classified vegetation as discussed by Daubenmire (1952), Driscoll and others (1984), and in the Forest Service Manual (Chapter 2060).

NEEDS OF THE LAND MANAGER

A basic use of associations by land managers is to serve as a framework for storage and retrieval of ecological information (Hall 1987) which can be used to: (1) characterize plant communities, (2) refine prediction of how a plant community will react to treatment, and (3) aid in development of prescriptions to attain management goals. Associations can be used to link silvicultural characteristics of forests together with other aspects of resource management such as livestock and wildlife use. When treatments of vegetation prove successful, they may be identified by associations for further reference. Past experience is documented for each association and refined solutions are described (not prescribed) for future use

This is accomplished by publishing a classification of plant communities including their descriptions with a key to their identification. Average site productivity potentials and management implications are included in the descriptions (Hall 1973; Hemstrom and others 1982; Hopkins 1979; Pfister and others 1977; Steele and others 1981; Volland 1985a). These are called "Plant Association Guides." Thus a silviculturist, range manager, and wildlife biologist can refer to the same Guide when considering options for treatment or land allocation.

Such a classification can aid the land manager, but it does not contain all information required. The land manager needs six kinds of resource information to make a sound decision:

1. Present vegetation: cover type, old growth forest, stagnated saplings, clearcut, current volume, presence and severity of disease, average stand diameter, forage rating, ecological status.

2. Topography (geometric classification): steepness of slope, aspect, length of slope, shape of slope (concave or flat or convex).

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Frederick C. Hall is Plant Ecologist, Pacific Northwest Region, Forest Service, U.S. Department of Agriculture, Portland, OR.

3. Soil characteristics: (Soil type) (Soil Survey Staff 1975): stability, ability to withstand traffic from vehicles and animals, erodability, moisture holding capacity, fertility.

4. Current use of the area: big game winter range, primary livestock range, active timber sale, endangered species area, insect outbreak.

5. Juxtaposition: location of the area in relation to roads, topographic features, water sources, or other vegetation types.

6. Association (plant community classification): characteristics of the potential plant community such as opportunities and limitations for management, plant community response to treatment, site potentials.

Used in conjunction with the other five items, associations give predictive power to land managers: potential problems may be identified and suitable treatment can be prescribed; opportunities for management can be described such as adapted species to plant or seed; and reactions of the plant community to harvest, reforestation, revegetation, fire, insects, and disease can be characterized (Arno and others 1985; Halverson and Emmingham 1982; Hopkins 1979).

CLASSIFICATION CONCEPTS IMPORTANT FOR APPLICATION

Land managers must deal with each and every acre under their jurisdiction, regardless of how typical or atypical the tract might be. Therefore, a continuum in potential natural or stable-state vegetation is a fundamental concept for classifying associations (Hall 1970). When natural potential cannot be sampled or identified, plant communities which appear to be in stable balance with their environment are selected (see Hall 1973, p. 43--Alpine fleeceflower[1]; Pfister and others 1977, pp. 115, 118-121--lodgepole pine; Steele and others 1981, pp. 82-85--lodgepole pine). Environmental gradients have long been recognized, such as change from north to west to south slopes, flat to steep slopes, and from low to high precipitation. Plant species react rather independently to these gradients, thus combining to form different kinds of potential natural plant communities. When combinations of environmental factors are similar, similar potential natural plant communities will result. When prominent breaks in the environment occur, such as across sharp ridgetops from north to south slopes, abrupt changes will occur in potential vegetation. Continuum gradients refer to the gradual change in potential natural communities one might see when sampling south slopes with similar soils over a 100-mile transect.

Sampling should encompass variability in the environment and plant communities to describe the natural changes in potential vegetation (Hall 1971). In order to describe an association, at least 10 sample plots are desirable. The variability may be evaluated with multivariate statistical analysis to develop plant associations based on numerical characteristics (Volland 1974; Volland and Connelly 1978). Each association must be identifiable in the field under most degrees of disturbance. This requires inclusion of major seral vegetation and characterization of topographic and soil features in the key to aid identification in poor forage rating condtions, nonpotential ecological status, or logged forest stands.

An "association" is not a real thing but rather a useful concept. It characterizes an average condition found in many sample plots which have been grouped together according to what the investigator perceives as a basic unit meeting the needs or objectives of the classification. It is an average description of a continuum segment with maximums and minimums for species density, composition, production, and reactions to treatment. Association averages will poorly describe potential natural ecosystems located mid-way on the continuum gradient between two associations. In some people's experience, about 30 percent of the time one will find plant communities in the field that do not easily fit an association description (Hall 1973). These stands are often referred to as ecotones, intergrades, or mixtures. One recommendation is to interpret or map them as the association most limiting to management.

A fundamental question among ecologists is what differentiates one association from another. Should it be based on presence/absence of plant species? Should associations be split for differences in dominance even though the same species are present? Should they be split for differences in production? Four criteria seem to be important for establishing associations when their primary use will be to evaluate and improve land management:

1. Limited variability in species dominance. This is a particularly important criterion for range management, as discussed later.

2. Limited variability in production of trees, shrubs, and herbs with a desired 95 percent confidence limit of less than ± 20 percent of the mean.

3. Distinct from other associations for important land management opportunities and limitations such as reaction to treatment, re-establishment of trees or other vegetation, or forage rating guides.

4. Identifiable on the ground in most stages of succession. The key to identifying associations must meet this need.

In general, classifications based on species presence or dominance are divided into more types based upon the above criteria (Arno and others 1985; Hall 1987). If differences in production and regeneration potential are desired outputs, they must be considered in the development of associations. Illustrations of these criteria will be discussed in range and timber management sections later in this paper.

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[1] Scientific names of species are listed after the references.

WILDLIFE MANAGEMENT

Wildlife respond more to stand structure or stand condition than to potential vegetation (fig. 1). In eastern Oregon for example, elk feed in clearcut areas or natural openings, hide in sapling stands, and take advantage of thermal cover in pole- to sawtimber-sized stands (Thomas and others 1979a). To a certain extent, rough topography may substitute for hiding cover. In summer, north slopes and upper draws can substitute for thermal cover while south slopes are used in winter.

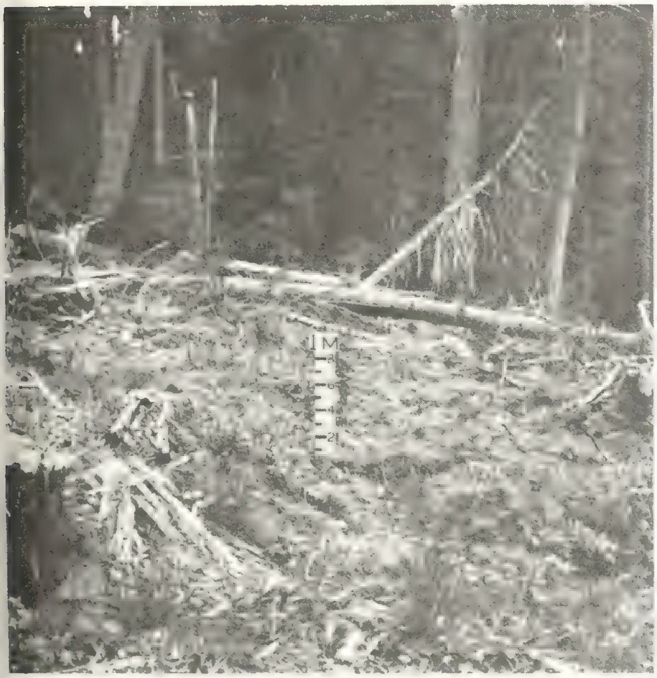

Figure 1--Clearcut in the white fir/big huckleberry association (Hall 1973). Many wildlife species using the old growth stand will not use the clearcut for reproduction and feeding.

In the Blue Mountains of Oregon, pileated woodpeckers prefer to nest in seral ponderosa pine or larch with an understory of fir. Being year-round residents, they depend upon heart-rotted snags and trees for carpenter ants, their staple winter food supply (Thomas and others 1979b). The association is important in regard to the potential opportunities characterized in its description.

For example, associations are useful in wildlife management if they have been adequately characterized for structural change with succession and reaction to treatment. They may be used to predict what kind of tree species, climax or seral, could be grown for those wildlife, like pileated woodpeckers, dependent on them.

Vegetation response to regeneration cutting will help predict production of palatable species and speed of successional change of the opening (Hall and Thomas 1979). In some cases, timber productivity can suggest opportunities and limitations for wildlife. For example, low site climax ponderosa pine will stagnate before it reaches the 70 percent crown cover desired for elk thermal cover. But on a good site where ponderosa pine is seral, it can be grown dense enough for elk thermal cover as well as to the 30-inch d.b.h desired by pileated woodpeckers for cavity excavation.

RANGE MANAGEMENT

Range management is the art and science of grazing livestock on uncultivated vegetation in ways that best maintain or improve the plant community. Forage rating is an ecological method for determing if current vegetation has the best species dominance and production possible for the site. Traditionally it was based upon potential natural plant communities--plant associations (Dyksterhuis 1949). Recently it has been updated to include two concepts: ecological status and resource value (Range Inventory Standardization Committee 1983). Ecological status compares the existing plant community with the potential natural vegetation of the site (association). Existing vegetation is classed as early, mid, or late seral or potential.

Resource values rate the existing plant community's ability to provide products and/or services for different purposes compared to the potential possible for the site. An existing plant community may be rated as good, fair, poor, or very poor for a specified purpose. The juniper/sagebrush/wheatgrass association is an example. A site supporting potential natural vegetation might rate good for wildlife habitat and only poor for livestock forage production. Eliminating juniper and sagebrush would probably double forage production for livestock, making it a good forage rating for livestock and only poor as wildlife habitat. Livestock forage ratings based on species composition will be illustrated.

The basic concept is this. When livestock overgraze an area in potential natural vegetation, they selectively kill out the most palatable species resulting in a change of species dominance in the plant community. These species are called decreasers (Dyksterhuis 1949). With continued overgrazing, even species of low palatability are killed (palatable increasers), further changing dominance and production (Dyksterhuis 1949). Figure 2 illustrates this change in dominance, measured by percent composition, for the ponderosa pine/wheatgrass/yarrow association (fig. 3). A good forage rating may be considered to be 75 to 100 percent of potential natural species composition, fair means some overgrazing has changed the plant community to 50 to 75 percent of potential, poor means serious past overgrazing has resulted in a decrease to 25 to 50 percent, and very poor indicates most palatable species are absent--serious deterioration of the plant community at less than 25 percent composition of potential natural vegetation.

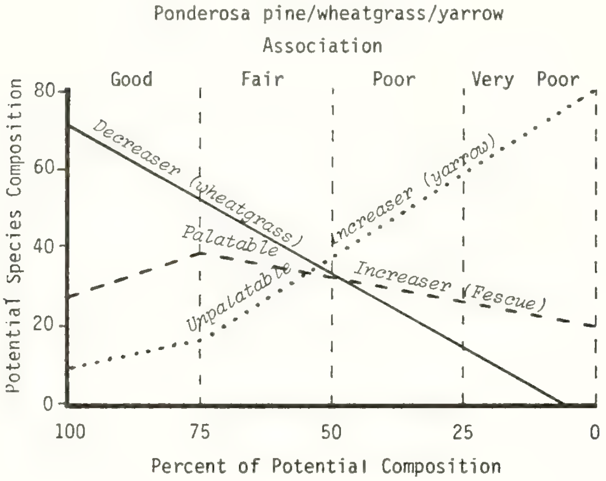

Figure 2--Method for estimating livestock forage rating based on composition. The most palatable species (wheatgrass) decreases with overgrazing. Less palatable species (fescue) increase temporarily, then decrease as they are grazed more heavily. Unpalatable species (yarrow) increase continuously.

Figure 3--Pondersosa pine/wheatgrass association (Hall 1973). Forage rating classes require this type be divided into more accurate associations as shown in table 2.

If an association is the basis for a forage rating guide, four forage rating classes impose predeterminded limits on the variability in species composition used to classify an association. In figure 2, good shows wheatgrass ranging from 53 to 67 percent composition, fescue from 26 to 34 percent, and yarrow from 6 to 14 percent composition. If a site has been correctly identified as representing the ponderosa pine/wheatgrass/yarrow association, it should have the potential for growing wheatgrass at 53 to 67 percent composition. If wheatgrass composition is less than 53 percent, one should assume that the forage rating is not good and that some past overgrazing has changed composition. Table 1 illustrates a forage rating guide for the ponderosa pine/wheatgrass/yarrow association

Table 1--Forage rating guide for ponderosa pine/wheatgrass/yarrow association based on composition of wheatgrass

Average potential natural composition:
Wheatgrass 60 percent
Fescue 30 percent
Yarrow 10 percent

Good rating	Wheatgrass	53-67%
Fair rating	Wheatgrass	35-52%
Poor rating	Wheatgrass	18-34%
Very poor rating	Wheatgrass	0-17%

The concept of four forage rating classes imposes statistical limits on how an association is developed. Since good represents 75 to 100 percent of potential, the range is 25 percent for an average of 82.5 ± 12.5 percent. Remember, the association is a conceptual description that is an attempt to characterize an unknown population of potential plant communities by a limited number of samples. As an estimate of a population, it should meet some set of statistical requirements. A choice is selection of an accuracy level, for example, a 95 percent confidence limit of ± 12.5 percent of the average composition of decreaser species.

This implies that when a site is correctly identified as being able to support a certain association, that site has the potential, 95 times out of 100, of actually being able to grow a species at a calculated level of composition. In the ponderosa pine/wheatgrass/yarrow association, a correctly identified site should have the potential of growing wheatgrass at 53 to 67 percent composition (a mean of 60 ± 7 percent where 12.5 percent of the mean is 60 x .125 = 7). The land manager does not know if the real site potential is 53 percent, 67 percent, or someplace in between.

Table 3--Six associations containing ponderosa pine with a site index class of 80 comparing selected characteristics (95 percent confidence intervals)

Association:	*Pipo/[1] Putr/ Feid	Pipo/[1] Putr/ Sihy-rhyolite	Pipo/[1] Putr/ Cape	Mixed[1] Conifer/ Arpa-Ceve	Mixed[1] Conifer/ Syal/ Caru	Mixed[2] Conifer/ Caru-ash soil
Status of pine:	Climax	Climax	Climax	Seral	Seral	Seral
Pine regeneration:	Easy	Severe-soil (frost heave)	Severe-sedge competition	Moderate	Moderate	Severe-grass competition
Wildlife use:	Winter-high	Low	Moderate	Summer-high	Moderate	Low
Growth basal area (ft^2)[3]	98 ± 8	91 ± 25	82 ± 19	209 ± 19	169 ± 55	124 ± 9
Site index (ft)	76 ± 3	74 ± 4	84 ± 2	83 ± 2	85 ± 8	76 ± 4
Production:						
Wood (ft^3)[4]	41 ± 4	38 ± 12	38 ± 9	97 ± 12	80 ± 32	53 ± 5
Herbage (lbs)	121 ± 19	31 ± **	51 ± 20	30 ± 16	12 ± **	330 ± 56
No. of plots:	43	3	10	21	5	33

[1] Volland 1985.

[2] Hall 1973.

[3] Stand basal area at which dominants grow at 1.0 inch per decade in diameter (Hall 1983).

[4] An index value computed as SI*GBA*.005 = ft^3 per acre per year.

* Pipo = ponderosa pine
Putr = bitterbrush
Feid = Idaho fescue
Sihy = squirreltail
Cape = long-stolon sedge
Arpa = greenleaf manzanita
Ceve = shinyleaf manzanita
Syal = snowberry
Caru = pinegrass

** Data too variable to calculate a 95 percent confidence interval.

reason, the Pacific Northwest Region's ecological classification program use four kinds of criteria for classifying an association: floristic similarity, productive similarity, similar management considerations, and identifiability in the field.

CONSIDERATIONS FOR VEGETATION MANAGEMENT

Data and interpretations for vegetation management must go into the classification so that management implications can be drawn from the classified units (associations). Classification of associations (lumping or splitting) can be influenced by factors in addition to presence or dominance of plant species.

Differences in productivity are just as ecologically oriented as are differences in species dominance (Hall 1971; Stage 1973, 1976). Regeneration characteristics are ecologically based as are revegetation opportunities (Halverson and Emmingham 1982). And seral reaction of plant communities are also environmentally influenced (Arno and others 1985).

Precision in association classification in the Pacific Northwest is designed for project level application, treatment of 10- to 40- acre tracts. National Forest and Regional plans require various groupings of associations for their broader application to 1,000- to 5,000- acre units. One problem has been to adequately define the question of what is wanted from the groups. Generally, a ma of associations has limited value above the Ranger District level (see Hemstrom and Frazier, these proceedings). Another problem is that management differences that could be used to distinguish associations may be unknown at the time of classification. This requires revision of the classification on a periodic basis.

SUMMARY

The primary purpose of plant association classification for land management is to store and retrieve management-related information used to characterize plant communities, predict plant community response to treatment, and aid prescription of treatment for attainment of a desired goal. Associations are used in conjunctio with present vegetation, topography, soil, current use, and tract location to refine management decisions. A philosophy of a continuum in potenti natural vegetation is assumed where sampling shoul encompass variability in vegetation and environment. Four criterion are used to establish an association: similar species dominance, limite variability in production, significant considerati for management, and identifiability in any stage o disturbance.

Wildlife respond more to stand condition or structure than to potential vegetation. Associations are useful in predicting habitat changes with succession or management and in characterizing opportunities and limitations of treatment to enhance wildlife habitat. Range management uses associations for forage rating guides that are based on species dominance or productivity. Four forage rating classes based on species dominance impose strict accuracy limits on composition of dominant species. This predetermined limit on variability must be a criteria for association classification. Associations are used in timber management to refine production estimates and depict regeneration characteristics in conjunction with other resource values such as herbage production and wildlife habitat.

REFERENCES

Arno, S.F.; Simmerman, D.G.; Keane, R.E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Driscoll, R.S.; Merkel, D.L.; Radloff, D.L.; Snyder, D.E.; Hagihara, J.S. 1984. An ecological land classification framework for the United States. Misc. Pub. No. 1439. Washington, DC: U.S. Department of Agriculture, Forest Service. 56 p.

Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. Journal Range Management. 2:104-114.

Hall, F.C. 1970. An ecological classification proposal and its importance to land management. In: Paulsen, H.A.; Reid, E.H., editors. Range and wildlife habitat evaluation: a reaserch symposium. Misc. Pub. 1147. Washington, DC: U.S. Department of Agriculture: p. 210-216.

Hall, F.C. 1971. Some uses and limitations of mathematical analysis in plant ecology and land management. In: Statistical ecology, Volume 3. Many species populations, ecosystems, and systems analysis. The Pennsylvania State University Press, University Park. p. 377-395.

Hall, F.C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R6 Area Guide 3-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 62 p.

Hall, F.C. 1983. Growth basal area: a field method for appraising forest site potential for stockability. Canadian Journal Forest Research. 13:70-77.

Hall, F.C. 1987. Pacific Northwest ecoclass codes for plant associations. R6-Ecol-T.P. 289-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Hall, F.C; Thomas, J.W. 1979. Silvicultural options. In: J.W. Thomas. ed., Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. Agr. Hndbk. No. 553. Washington, DC: U.S. Department of Agriculture, Forest Service, p. 128-147.

Halverson, N.M.; Emmingham, W.H. 1982. Reforestation in the Cascades Pacific silver fir zone. R-6 Ecol. 091-1982. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 37 p.

Hemstrom, M.A.; Emmingham, W.H.; Halverson, N.W.; Logan, S.E.; Topik, C. 1982. Plant association and management guide for the Pacific silver fir zone, Mt. Hood and Willamette National Forests. R6-Ecol. 100-1982a. Portland, OR: U.S. Department of Agriculuture, Forest Service, Pacific Northwest Region. 104 p.

Hopkins, W.E. 1979. Plant associations of the Fremont National Forest. R6-Ecol-79-004. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 106 p.

Pfister, R.D.; Kovalchik, B.L.; Arno, S.F.; Presby, R.C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Range Inventory Standardization Committee. 1983. Guidelines and terminology for range inventories and monitoring. Society for Range Management, presented to the Board of Directors of SRM, Albuquerque, NM. February, 1983. 13 p.

Soil Survey Staff. 1975. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agr. Hndbk. No. 436. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 753 p.

Stage, A.R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Stage, A.R. 1976. An expression for the effect of aspect, slope, and habitat type on tree growth. Forest Science. 22:457-460.

Steele, R.; Pfister, R.D.; Ryker, R.A.; Kittams, J.A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Thomas, J.W.; Black, H., Jr.; Scherzinger, R.J.; Pedersen, R.J. 1979a. Deer and Elk. In: J.W. Thomas, ed., Wildlife habitats in managed forests, the Blue Mountains of Oregon and Wahsington. Agr. Hndbk. No. 553, Washington, DC: U.S. Department of Agriculture, Forest Service: p. 104-127.

Thomas, J.W.; Anderson, R.G.; Maser, C.; Bull, E.L. 1979b. Snags. In: J.W. Thomas, ed., Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. Agr. Hndbk. No. 553. Washington, DC: U.S. Department of Agriculture, Forest Service: p. 60-77.

Volland, L.A. 1974. A multivariate classification of lodgepole pine type in central Oregon with implications for natural resource management. Fort Collins, CO: Colorado State University. 250 p. Dissertation.

Volland, L.A. 1985a. Plant associations of the central Oregon pumice zone. R6-Ecol-104-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 113 p.

Volland, L.A. 1985b. Guidelines for forage resource evaluation within central Oregon pumice zone. R6-Ecol-177-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 216 p.

Volland, L.A.; Connelly, M. 1978. Computer analysis of ecological data: methods and programs. R6-Ecol 79-003. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 350 p.

PLANT SPECIES MENTIONED

Alpine fleece flower	Polygonum phytolaccaefolium (Mein. ex Small)
Big huckleberry	Vaccinium membranaceum (Dougl. ex Hook)
Bluegrass	Poa pratensis (L.)
Bitterbrush	Purshia tridentata (Pursh.)
Ceanothus	Ceanothus velutinus (Dougl. ex Hook)
Cheatgrass	Bromus tectorum (L.)
Douglas-fir	Pseudotsuga menziesii var. glauca (Beissn.)
Fescue	Festuca idahoensis (Elmer)
Fir	Abies grandis, Pseudotsuga menziesii
Juniper	Juniperus occidentallis
Larch	Larix occidentalis (Nutt.)
Lodgepole pine	Pinus contorta var. latifolia (Engl. ex Louden)
Long-stolon sedge	Carex pennsylvanica (Boeck.)
Manzanita	Arctostaphylos patula (Greene)
Mixed conifer	Abies spp., Pseudotsuga, Pinus spp.
Pinegrass	Calamagrostis rubescens (Buckl.)
Ponderosa pine	Pinus ponderosa (Dougl. ex Loud)
Rabbitbrush	Chrysothamnus nauseosus (Pall.)
Sagebrush	Artemisia tridentata
Snowberry	Symphoricarpos albus (Blake)
Squirreltail	Sitanion hystrix (Nutt.)
Wheatgrass	Agropyron spicatum (Scribn. & Smith)
White fir	Abies grandis (Lindl.)
Yarrow	Achillea millefolium (L.)

CLASSIFICATION AND MODELS OF SUCCESSION

David W. Roberts and Penelope Morgan

ABSTRACT: Approaches to the study of successional vegetation are compared and evaluated. Mechanistic and empirical philosophies are contrasted, as are classification and modeling methods. Examples are drawn from successional studies in the northern Rocky Mountains of the United States. An approach that takes advantage of the strengths of the different approaches is recommended for future work.

INTRODUCTION

There are almost as many methods for studying succession as there are investigators. The two most common methods, classification and modeling, have different objectives and emphasize different aspects of succession. Either of these two methods may be employed under a mechanistic or empirical philosophy, and the choice of philosophy will also influence the results. The objective of this paper is to compare and evaluate these contrasting approaches to the study of vegetation dynamics. We illustrate the relative advantages and disadvantages with examples of succession research in the northern Rocky Mountains. We focus primarily on applied succession research, but generally omit stand development and growth-and-yield models developed primarily for timber management objectives.

EMPIRICAL AND MECHANISTIC PHILOSOPHIES

Empirical classifications or models are based primarily upon observations of the relations between chosen variables, without explicit representation of the mechanisms of succession. Typically, large numbers of vegetation samples are observed under a random or stratified-random sampling scheme; the observed variables are chosen based on experience and past research. The vegetation samples are analyzed statistically; multivariate procedures are commonly used. The classification or model then summarizes the observed relations.

Mechanistic classifications or models are based on a chosen theory of the causes and mechanisms of succession, such as Noble and Slatyer's (1980) concepts of inhibition, tolerance, and facilitation or Botkin's (1981) concepts of differential response to resource availability. A conceptual classification or model is developed from the theory, and vegetation is sampled to calibrate or to test the conceptual classification or model. The structure of the mechanistic model or classification is determined by the theory, rather than by observation.

No existing research falls entirely into either school. Instead, most are situated along a continuum between the poles (fig. 1). Our distinction is deliberately polar to heighten the contrast between studies using predominantly one of the two philosophies.

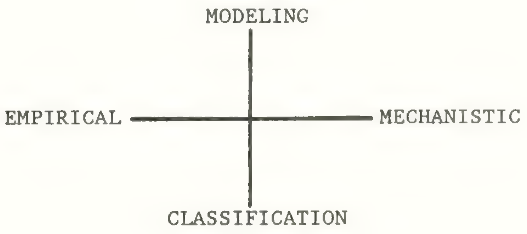

Figure 1--Contrasting approaches to studies of succession.

SUCCESSIONAL VEGETATION CLASSIFICATION

Classification of variability in natural vegetation has proven useful in land management (Layser 1974). Classifications of potential vegetation have been developed for much of the Rocky Mountains and northwestern United States (Pfister 1982). These classifications have demonstrated that despite controversy surrounding the inherent nature of vegetation distribution, classification provides a framework for communicating and enhancing ecological understanding.

It seems logical, therefore, that classification may also prove useful for describing successional vegetation, especially if the vegetation is stratified by plant association (Steele 1984). This reduces the variability among seral communities and identifies the endpoint of succession, the potential vegetation type.

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David W. Roberts is Assistant Professor, Department of Forest Resources and Ecology Center, Utah State University, Logan UT; Penelope Morgan is Assistant Professor, College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow, ID.

Empirical Classifications

Empirical classifications are commonly developed using multivariate statistical techniques, such as cluster analysis and ordination. These techniques can be used to determine successional classes objectively and to summarize the characteristics of these classes. The techniques are well understood and this approach is efficient, leading to relatively robust results. Although investigator bias is minimized, it should not be assumed that total objectivity is achieved, for selection of variables and choice of analyses influences the structure of the resulting classification.

The primary limitation from an operational point of view is the difficulty of extrapolating results. Because empirical analyses are not based on mechanism, it is difficult to determine where outside the original study area the results may apply. Even within the study area, there is no basis for predicting vegetation dynamics under conditions not previously observed. This can lead to a multiplicity of classifications, each of which is specific to a narrow range of environments, disturbance types, and vegetation.

This philosophy has been employed in classification of successional vegetation by Arno and others (1985).

Mechanistic Classifications

The mechanistic approach employs ecological theory to predetermine the structure of the classification. The chosen theory is used to generate predictions about the temporal behavior of vegetation; the predictions are then organized into classes on the basis of similar predicted outcome. Unfortunately, there is no universally accepted ecological theory to employ, and subjective choices must be made between competing hypotheses or theories. Potentially, this leads to investigator bias, as these choices jointly determine the structure of the classification. If the chosen theory is subsequently discredited, or not accepted by other scientists, the utility of the classification becomes suspect.

The primary advantage of the mechanistic approach is the greater ease with which results can be extrapolated. As long as the same mechanisms are operable, the results should apply outside the immediate study area. Additionally, it is possible to hypothesize combinations of environmental factors or disturbance regimes never observed, and to predict vegetation composition for these sites. Then, if these new sites are observed, they are already included in the classification system.

The primary disadvantage of the mechanistic approach is that even with a few essential mechanisms, numerous successional community types may be predicted, some of which are rare or nonexistent (Steele 1984). This leads to two problems. First, the classification may be overly complex, and given our limited understanding of the relationships involved, a simpler approach may be preferable. Second, there may be many classes with too few samples, which limits the reliability of predictions about the characteristics of such classes.

Huschle and Hironaka (1980), Steele (1984), and Steele and Geier-Hayes (1987) used the mechanistic approach to classify successional vegetation.

MODELING OF SUCCESSIONAL VEGETATION

Succession models predict changes in vegetation with time, and range from conceptual models (Cattelino and others 1979, for example) to detailed computer models (for instance, see Keane 1987). The predicted species composition may be based upon the response of individual species, or may be based on species groups or life forms. Many models have focused exclusively on tree species, but a few have been more comprehensive.

Empirical Models

In empirical succession models, future vegetation composition is predicted based on observed relationships of site attributes, disturbance characteristics, existing vegetation, and other variables. Many are regression models, which predict the abundance of one or more species (for example, Irwin and Peek 1979; Keane 1987). Several distinct regression models may be hypothesized; these can be tested to see which yields the best predictions. Alternatively, the probability of transition from one successional community to another can be measured and employed in a Markov chain model (Hulst 1979), or the rate of transition can be used in a differential equation model (Shugart and others 1973).

Few complex models are entirely empirical. For instance, the Stand Prognosis Model projects tree and stand development (Wykoff 1986; Wykoff and others 1982), tree regeneration (Ferguson and Crookston 1984; Ferguson and others 1986) and occurrence, biomass, and cover of some understory species (Moeur 1985), based on site attributes, habitat type, and disturbance or management. The functional relationships were empirically estimated using regression (usually nonlinear) techniques, but the particular functions were constrained by known or hypothesized relationships. Thus, models with the "best fit" statistically were not used if their predictions were inconsistent with available qualitative knowledge (Stage 1988).

Empirical models share most of the advantages and disadvantages of classifications developed under the same philosophy. These models benefit from the widespread availability of statistical tools, and they are relatively objective and efficient. Extrapolation of model predictions may be seriously in error, however, and care must be taken to avoid overfitting statistical models by using too many independent variables with too few samples (Verbyla 1986).

It is important that the assumptions on which a given statistical technique is based are appropriate to the vegetation structure and distribution, or that the technique is sufficiently robust. For instance, many models are based on an assumption of linear or monotonic response of vegetation composition to environmental gradients or disturbance factors, which may be inappropriate (see Roberts and Cooper, this proceedings).

Mechanistic Models

Many forest simulation models have been developed under the mechanistic philosophy. Botkin and others (1972) pioneered a model paradigm, JABOWA, that simulates the birth, growth, and death of individual trees in a stand. This model explicitly incorporates the effects of light and moisture availability on photosynthetic response and growth rate. Related models have included other environmental factors ranging from nutrient availability (Aber and Melillo 1982; Pastor and Post 1986) to fire response (Kercher and Axelrod 1984), as well as the long-term effects of forest management practices (Aber and others 1979, 1982).

While this model paradigm has provided insight into the possible effects of disturbance or management in a variety of forest ecosystems (Shugart 1984), there are some practical limitations. First, the models are data intensive, requiring quantitative estimates of each species' response to environmental factors and other autecological information. Often these data do not exist and may be difficult to obtain. Second, the model structure is designed primarily for tree species. While it should be possible to modify the program for other life forms, it will be difficult given the current complexity of the model. Third, the model is computationally intensive. The model is stochastic and requires averaging the numerous replicate simulations to produce estimates of expected values. Steinhorst and others (1985) simulated shrub response to clearcutting and burning. The model combines stochastic and deterministic elements to predict the probability of establishment and subsequent growth of individual shrub species. Predictions are made of the shrub community composition for 15 years following burning. Predicting response of only a part of the vegetation to only some kinds of disturbance may be more effective than developing larger, more general models.

Other mechanistic models are based on the vital attributes concept of Noble and Slatyer (1980). These models produce qualitative estimates of tree species abundance (Cattelino and others 1979) or semi-quantitative predictions of abundance of all species (Kessell and Potter 1980) for vegetation subjected to recurrent disturbance. These models are graphical, rather than computer-based, which increases their utility and intuitive appeal for many users. They lack detail necessary for some purposes, however. Roberts (1987) developed a stochastic simulation model based on the vital attributes paradigm which removes some of the limitations, but a computer is required. These models produce semi-quantitative predictions useful for land managers, they have minimal data requirements, which can easily be determined or estimated, and they are computationally efficient.

DISCUSSION

Developers and users of successional classifications and models need to be aware of the advantages and disadvantages of each method and philosophy. The purpose for which the classification or model will be used, time available, and costs of development will constrain the choices. Careful design based upon extensive forethought will greatly increase the utility of the end result.

Empirical Versus Mechanistic Philosophies

Throughout this paper, we have deliberately emphasized distinctions between philosophies of succession research. In practice, these philosophies are often combined very effectively. Mechanistic classifications or models require empirical data for calibration and validation. Empirical classifications or models require theory to suggest which variables are essential for inclusion and to evaluate model behavior.

Empirical methods are well suited to specific applications, or to situations where the relevant theories are not sufficiently developed to guide mechanistic model or classification development. These methods are based on observation, which imparts two critical characteristics. First, sampling design, (the degree of randomization, the stratification criteria, and the definition of the target population) is very important, as it determines the observations made. Second, the extent to which observations of the past and present provide a reasonable basis for predicting the future must be determined. The conditions under which vegetation develops presently are different from the past. Widespread fire suppression is ecologically unprecedented, and silvicultural practices produce vegetation communities that may never have existed previously.

Mechanistic approaches are appropriate for more general or comprehensive applications, or for problems where detailed data for development of an empirical classification or model are lacking. Mechanistic approaches are based on theory, and the success of this approach will depend on the applicability of current theories to the local situation, and the skill of the developer in implementing the selected theories as a model or classification.

Research in natural resources has generally shown that when the primary objective is accurate prediction of specific variables, empirical approaches are superior. When the primary objective is increasing our understanding of complex systems, or predicting the behavior of a system outside the range of observation, mechanistic models are preferable.

Classification Versus Modeling

Classification of successional vegetation can produce benefits similar to those derived from classification of potential vegetation: increased ecological understanding and a framework for communication. However, successional vegetation is dynamic, so classifications have increased utility if there is an indication of how long a community will stay in a given class, and to which class it may subsequently belong. Ideally, we would like to know the entire sequence of successional development, called the pathway by Arno and others (1985). If the pathway is branched, probabilities can be assigned to the multiple pathways of successional development.

Alternatively, simulation models provide a more natural analog for successional dynamics. There now exists a considerable knowledge base for the development and application of such models. Many existing models of succession have a mix of resolution; individual trees are modeled in great detail while detail on other life forms is minimized or omitted. Many of these models also have extensive data requirements, and produce information difficult to interpret in a management context.

RECOMMENDATIONS

Based on our assessment of the relative advantages of each approach and the information needs of land managers, we suggest the following. Employing a mechanistic approach, develop a simple conceptual model which identifies the main successional pathways and partitions the successional vegetation into a moderate number of possible states or classes. When defining pathways, limit each attempt to the possible pathways that lead to a single plant association. Ensure that the model is comprehensive and general enough to accommodate the entire range of possible successional communities. Then, from the conceptual model develop a simple simulation model that predicts the rate and pathway of transition among the individual classes or states based upon responses of individual or groups of species. Then, employing an empirical approach, collect sufficient data to characterize the vegetation composition for the observed states of the model. Additional resource values (such as big game hiding cover or recreation potential) can be predicted indirectly from the predicted vegetation composition and structure. Validate the model based upon data independent of that used in model construction, and refine the model where necessary.

We believe this approach will produce tools useful to land managers in a broad range of vegetation types with relatively few years of effort. It will incorporate our understanding of successional processes, yet be efficient in terms of vegetation sampling and analysis. The models will be sufficiently simple that the computational requirements will be easily met, and will produce information in a form useful to land managers.

REFERENCES

Aber, J. D.; Melillo, J. M. 1982. FORTNITE: A computer model of organic matter and nitrogen dynamics in forest ecosystems. Research Division Bulletin. Madison, WI: University of Wisconsin, College of Agricultural Science. R3130: 1-49.

Aber, J. D.; Botkin, D. B.; Melillo, J. M. 1979. Predicting the effects of different harvesting regimes on productivity and yield in northern hardwoods. Canadian Journal of Forest Research. 9: 10-14.

Aber, J. D; Melillo, J. M.; Federer, C. A. 1982. Predicting the effects of rotation length, harvest intensity, and fertilization on fiber yield from northern hardwood forests in New England. Forest Science. 28: 31-45.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Botkin, D. B. 1981. Causality and succession. In: West, D. C.; Shugart, H. H.; Botkin, D. B., eds. Forest succession: concepts and application. New York, Springer-Verlag: 36-55.

Botkin, D. B.; Janak, J. F.; Wallis, J. R. 1972. Some ecological consequences of a computer model of forest growth. Journal of Ecology. 60: 849-872.

Cattelino, P. J.; Noble, I. R.; Slatyer, R. O.; Kessell, S. R. 1979. Predicting the multiple pathways of succession. Journal of Environmental Management. 3: 41-50.

Ferguson, D. E.; Crookston, N. L. 1984. User's guide to the regeneration establishment model--a prognosis model extension. Gen. Tech. Rep. INT-161. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Ferguson, D. E.; Stage, A. R.; Boyd, R. J. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. Forest Science Monograph 26. 41 p.

Hulst, R. van. 1979. On the dynamics of vegetation: Markov chains as models of succession. Vegetatio. 40: 3-14.

Huschle, G.; Hironaka, M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33: 179-182.

Huston, M.; Smith, T. 1987. Plant succession: life history and competition. American Naturalist. 130:168-198.

Irwin, L. L.; Peek, J. M. 1979. Shrub production and biomass trends following fire and logging treatments within the cedar-hemlock zone of northern Idaho. Forest Science. 25: 415-426.

Keane, R. E. II; 1987. Forest succession in western Montana--a computer model designed for resource managers. Res. Note INT-376. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Kercher, J. R.; Axelrod, M. C. 1984. Analysis of SILVA: A model for forecasting the effects of SO^2 pollution and fire on western coniferous forests. Ecological Modelling. 23: 165- 184.

Kessell, S. R.; Potter, M. 1980. A quantitative model of nine Montana forest communities. Journal of Environmental Management. 4: 227-240.

Layser, E. G. 1974. Vegetative classification: its application to forestry in the northern Rocky Mountains. Journal of Forestry. 72: 354-357.

Moeur, M. 1985. COVER: A user's guide to the CANOPY and SHRUBS extension of the stand prognosis model. Gen. Tech. Rep. INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 49 p.

Noble, I. R.; Slatyer, R. O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio. 43: 5-21.

Pastor, J.; Post, W. M. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. Biogeochemistry. 2: 3-27.

Pfister, R. D. 1982. Designing successional models to meet management needs. In: Means, J. E., ed. Forest succession and stand development research in the Northwest: symposium proceedings; 1981 March 26; Corvallis, OR: Oregon State University: 44-53.

Pickett, S. T. A.; Collins, S. L.; Armesto, J. J. 1987. Models, mechanisms and pathways of succession. Botanical Review. 53: 335-371.

Roberts, D. W. 1987. VITAL: a forest succession model based on vital attributes theory. Logan, UT: Department of Forest Resources, Utah State University. Unpublished report.

Shugart, H. H. 1984. A theory of forest dynamics. New York: Springer-Verlag. 278 p.

Shugart, H. H.; Crow, T. R.; Hett, J. M. 1973. Forest succession models: a rationale for modeling forest succession over large regions. Forest Science. 19: 203-212.

Stage, A. R. 1988. [Personal communication]. January. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

Steele, R.; Geier-Hayes, K. 1987. The grand fir/blue huckleberry habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

Steinhorst, R. K.; Morgan, P.; Neuenschwander, L. F. 1985. A stochastic-deterministic model of shrub succession. Ecological Modelling. 29: 35-55.

Verbyla, D. 1986. Potential regression and discriminant analysis. Canadian Journal of Forest Research. 16: 1255-1257.

Wykoff W. R. 1986. Supplement to the user's guide for the Stand Prognosis Model--Version 5.0. Gen. Tech. Rep. INT-208. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 36 p.

Wykoff, W. R.; Crookston, N. L.; Stage, A. R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

INFLUENCE OF BIOLOGICAL LEGACIES ON SUCCESSION

Jerry F. Franklin and Charles B. Halpern

ABSTRACT: Survival of indicator plant species was addressed in a long-term study of succession after clearcutting and slash burning in Douglas-fir forests. Very dry or very moist habitats returned to classifiable states more rapidly than less harsh environments. Areas with sparse understory before logging were slowest to return to classifiable states.

Predisturbance ecosystems typically have major influences on the pathways and rates of succession after a catastrophic disturbance. Much of this influence is related to "biological legacies," organisms or organic structures and influences that persist through the disturbance. Indeed, a disturbance can be viewed as an editing process in which selected elements of the predisturbance ecosystem are carried into and influence the recovery process. The importance of biological legacies has been demonstrated in seres after natural large-scale catastrophic events (for example, the eruption of Mount St. Helens) and after typical forest clearcutting.

Important biological legacies include living organisms, structures, and spatial patterns. Living legacies include green plants, animals, seed banks, and fungi. Important animal and fungal components may include pests and pathogens, as well as mycorrhizal fungi. Numerous organisms survived the catastrophic eruption of Mount St. Helens as a result of many different strategies and circumstances (Franklin and others 1985). Dead organic legacies include fine organic matter, as well as structures such as standing dead trees, downed boles (coarse woody debris), and large soil aggregates. Coarse woody debris is critical as habitat for many heterotrophs and for many other ecological functions (Harmon and others 1986). Spatial patterns include soil patterns that are associated with individual trees and patterns in composition and density of understory vegetation associated with overstory canopy density (shading). Western hemlock and western redcedar provide an outstanding example of the contrasting effects of tree species on soil chemical, physical, and microbiological properties (Alban 1969; Turner and Franz 1985). Areas of greater sunlight (gaps) and of dense shading (antigaps) produce contrasting legacies. For example, at the H. J. Andrews Experimental Forest in the western Cascade Range of Oregon, heavily shaded areas belonging to the Tsuga heterophylla series (referred to as the Coptis laciniata, or Goldthread community, by Dyrness 1973) have depauperate understories; after clearcutting, tree regeneration is typically more successful on such sites because of the lack of competing herbs and shrubs.

A major issue in vegetation classification is identification of habitat types early in succession. Hence, a biological legacy of particular interest is persisting indicator species. Their survival was addressed in a long-term study of succession after clearcut logging and slash burning in Douglas-fir forests at the H. J. Andrews Experimental Forest (Dyrness 1973; Halpern 1987). A total of 192 permanent 2 x 2 m sample plots were established in undisturbed forest; changes in vegetation have been observed since the plots were logged and burned during 1962-66.

Analyses considered the period of time before plots returned to an identifiable state, with habitat type and disturbance intensity as major variables. Results showed that more extreme habitats (very dry or very moist) returned to a classifiable state more rapidly than modal sites, partially because modal environments depend more heavily on relative coverage of widespread species for identification (i.e., lack high-fidelity species). Areas that had depauperate understories before logging (antigaps) were slowest to return to an identifiable state after disturbance. Generally, recovery period increased with increasing disturbance intensity.

REFERENCES

Alban, D. H. 1969. The influence of western hemlock and western redcedar on soil properties. Soil Science Society of America Proceedings. 33: 453-459.

Dyrness, C. T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology. 54: 57-69.

Paper presented at the Symposium on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Jerry F. Franklin is Bloedel Professor of Ecosystem Analysis, College of Forest Resources, University of Washington, Seattle, WA, and Chief Plant Ecologist, USDA Forest Service, Pacific Northwest Research Station. Charles B. Halpern is Post-doctoral Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR.

Franklin, J. F.; MacMahon, J. A.; Swanson, F. J.; Sedell, J. R. 1985. Ecosystem responses to the eruption of Mount St. Helens. National Geographic Research. 1: 199-216.

Halpern, C. B. 1987. Twenty-one years of secondary succession in Pseudotsuga forests of the western Cascade Range, Oregon. Corvallis, OR: Oregon State University. 239 p. Dissertation.

Harmon, M. E.; Franklin, J. F.; Swanson, F. J.; [and others]. 1986. Ecology of coarse woody debris in temperate ecosystems. In: MacFadyen, A.; Ford, E. D., eds. Advances in Ecological Research. Orlando, FL: Academic Press, Inc.: 133-302. Vol. 15.

Turner, D. P.; Franz, Eldon H. 1985. The influence of western hemlock and western redcedar on microbial numbers, nitrogen mineralization, and nitrification. Plant and Soil. 88: 259-267.

CLASSIFICATION AND PREDICTION OF SUCCESSIONAL PLANT COMMUNITIES USING A PATHWAY MODEL

Robert E. Keane

ABSTRACT: This paper describes a successional classification system that identifies successional communities and sequences of communities called pathways within a habitat type. This classification links treatment, site, and vegetation factors to construct a conceptual model of succession for four habitat types common to west central Montana. A computer model (FORSUM) was developed from this classification system that predicts coverage of plant species based on treatment and predisturbance plant composition. Testing shows that FORSUM averaged 74 percent accuracy in predicting species cover. Predictions from this model are useful in land management and planning. FORSUM is widely available for several computer systems.

INTRODUCTION

Land classifications using the habitat type approach (for example, Pfister and others 1977) describe the potential vegetation of a land unit but provide limited information on the composition of the seral communities occupying much of the area within a habitat type. Identification of successional communities is important in land management planning because types of silvicultural treatments strongly influence successional community sequences across the landscape (Cholewa and Johnson 1983; Fischer and Bradley 1987; Stickney 1980; Zamora 1975). Understanding successional sequences, termed "pathways" in this paper, is of great importance for management of timber, wildlife habitat, range, watershed and recreational resources. Classification of seral communities will allow a means of identifying and mapping current vegetation. Arranging the sequence of seral communities along a pathway and then quantifying species cover changes along the pathway provides a useful predictive tool for forest land management.

The conceptual successional pathway model presented in this paper is composed of a discrete set of vegetation communities sequentially linked in succession-time by successional pathways (Arno and others 1985). These pathways begin with pioneer plant communities arising immediately after a major disturbance and terminate with the near-climax or long-term stable community. This approach is quite similar to that taken by Cattelino and others (1979) and Kessell and Fischer (1981). An important feature of this conceptual pathway model is that predisturbance vegetation, site factors, and disturbance characteristics are recognized as influencing pathway origin and direction. This facilitates the quantification of the conceptual model to an empirical model using the data collected for the classification (Keane 1987).

This paper describes how the pathway approach was used in the development of a successional communit classification system for four major habitat types in west central Montana. In addition, an accompanying computer model, called FORSUM, is presented. This computer model was created from the conceptual pathway model using empirical data. It is a useful predictive tool applicable to many resource management concerns.

CONCEPTUAL MODEL

Sampling--Development of this pathway model required extensive data collection. Many plant communities resulting after different stand-replacing silvicultural treatments (table 1) or wildfire were sampled using techniques describe by Arno and others (1976) and Pfister and Arno (1980). In addition, adjacent mature and postdisturbance communities on the same physical site were sampled to reduce variability between individual sites within a habitat type (Arno 1981; Zamora 1975). Site characteristics, disturbance histories, and coverages of individual species wer recorded for each stand (Arno and others 1985).

To minimize regional floristic differences, vegetation sampling was restricted to an area of approximately 5 million acres in western Montana, relatively homogeneous in geology, macroclimate, and physiography (fig. 1). Sampling was confined to four common habitat types (table 2) which comprise over half of the forested acres in this area.

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Robert Keane is a Quantitative Ecologist working in association with the Northern Region's Ecosystem Management Program and the Intermountain Research Station's Intermountain Fire Sciences Laboratory, Forest Service, U.S. Department of Agriculture, Missoula, MT.

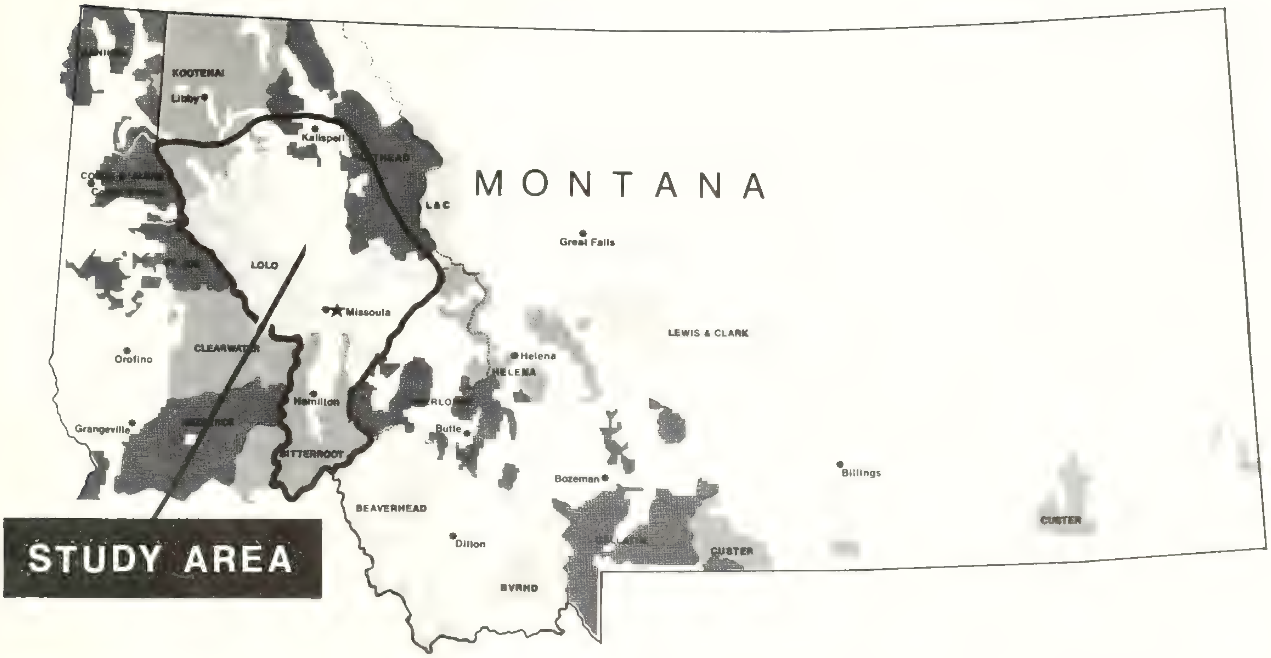


Figure 1--Sampling area for the succession classification and computer model. Application of the classification or model outside the study area is not advisable.

Classification--Data collected from 774 stands were scrutinized to determine if successional development could be described fully, based upon the existing habitat type classification (Pfister and others 1977). In some cases additional refinement of habitat types at the phase level was made to define more appropriate potential climax types for this limited area (Arno and others 1985). Then, based upon results of ordination analyses (Gauch 1984), synthesis table analyses (Mueller-Dombois and Ellenburg 1974), and index-of-similarity calculations (as outlined in Pfister and Arno 1980), sampled stands were grouped into community types based on dominant or diagnostic plant species.

Table 1--Types of silvicultural treatments and natural disturbances used in the succession classification and model. All disturbances can be initiated at one of three severities. The severities are low or light, moderate or medium, and high or heavy. Criteria used to assess disturbance severity are outlined in Keane (1987)

Treatment Code	Treatment Type
WF	Wildfire; must be a stand-replacing fire.
BB	Clearcut and broadcast burn; all trees must be removed.
MS	Clearcut and mechanical scarification; all trees are removed. Includes pile-and-burn treatments.
NP	No site preparation implemented on site after clearcut.

Community type names were assigned by identifying the dominant overstory and the diagnostic undergrowth plants. For example, a community dominated by Pinus contorta (PICO or lodgepole pine) in the overstory and Calamagrostis rubescens (CARU or pinegrass) in the undergrowth would be named PICO/CARU. Communities with no overstory cover had only one species in the name (e.g. CARU), and communities with shared dominance by two or more species had hyphenated names (for example, PICO-PSME/CARU-XETE).

Table 2--List of potential vegetation types included in the successional classification and model. The list includes the phases of each type that was sampled. See Arno and others (1985) for explanation of the potential vegetation types as they relate to habitat types

Potential Veg Type	Phase Code	Scientific Name	Common Name
PSME/PHMA	DRY	Pseudotsuga menziesii/ Physocarpus malvaceus, dry	Douglas-fir/ ninebark, dry
PSME/PHMA	MOIST	Pseudotsuga menziesii/ Physocarpus malvaceus, moist	Douglas-fir/ ninebark, moist
PSME/VAGL	XETE	Pseudotsuga menziesii/ Vaccinium globulare, Xerophyllum tenax	Douglas-fir, huckleberry, beargrass
ABLA/XETE	VAGL	Abies lasiocarpa/ Xerophyllum tenax, Vaccinium globulare	subalpine fir/ beargrass, huckleberry
ABLA/XETE	VASC	Abies lasiocarpa/ Xerophyllum tenax, Vaccinium scoparium	subalpine fir/ beargrass, whortleberry
ABLA/MEFE	WARM	Abies lasiocarpa/ Menziesia ferruginea, warm	subalpine fir/ menziesia,
ABLA/MEFE	COLD	Abies lasiocarpa/ Menziesia ferruginea, cold	subalpine fir/ menziesia, cold

Pathway Delineation--Successional pathways were identified by analysis of the data for all stands within each community type for a specific habitat type phase. First, stands within individual pathways were ordered along a successional gradient using the following stand data: 1) tree canopy cover (%); 2) average d.b.h. (diameter at breast height) of dominant trees (inches); 3) basal area (ft^2/acre); and 4) stand age or years since last major disturbance. These stand characteristics were used to define five structural stages or nodes of successional development along a pathway (fig. 2). These ordered communities were then sorted into pathways based on species composition and autecology of the diagnostic plant species. A hypothetical example of pathways within a habitat type is shown in figure 3. Stepwise keys using species coverage as criteria were constructed to identify the successional pathways (fig. 4)

It was assumed all successional pathways converged on or near a climax community type (habitat type or phase) defined by a particular vegetational composition (Arno and others 1986). The point along the successional gradient at which pathways converge was estimated based upon inspection of the composition of stands at different ages. The resulting classification contains community types arranged along succession pathways by structural stages (fig. 5).

Relating Treatment to Pathway--After the classification was developed, the kind and severity of treatments were linked to the initial, posttreatment community type of each pathway. Treatment histories, site characteristics and species compositions of sampled stands in the paired post- and pre-disturbance communities were inspected to determine which kinds of conditions were associated with the origin of a given pathway (Arno and others 1985, Keane 1984). Although treatments were often not strongly correlated with pathway origin, a set of guidelines was formulated to describe the usual conditions or treatments apparently influencing successional direction. These guidelines were then integrated into the classification as a part of the successional diagram called the Conditions or Treatment Box (fig. 6).

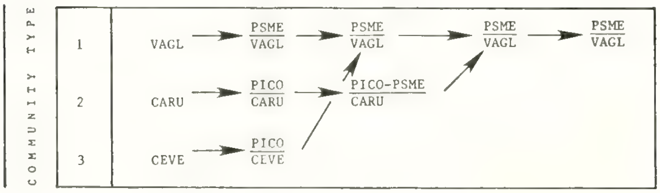


Figure 2--An example of three successional pathways within a hypothetical habitat type phase or potential vegetation type. Each pathway is composed of five successional communities linked by arrows. Species code definitions: VAGL - Vaccinium globulare, CARU - Calamagrostis rubescens, CEVE - Ceanothus velutinus, PSME - Pseudotsuga menziesii, and PICO - Pinus contorta.

Stand characteristics	STRUCTURAL STAGES				
	Shrub-herb	Sapling	Pole	Mature seral forest	Old-growth forest
Tree canopy cover (percent)	0-15	15-90	50-90	50-80	50-70
d.b.h. of dominant trees (inches)	0-1	2-5	6-10	11-15	16-25
Basal area (ft^2/acre)	0-1	2-100	100-250	100-250	150-250
Age (yr)	5-15	15-30	30-100	100-200	200-300

Figure 3--Structural stages describing a successio pathway in time. Example ranges of stand characteristics are shown within the diagram.

Final Classification--The successional classification for each habitat type phase include the successional diagram (fig. 5), pathway keys (fig. 4), treatment associations (fig. 6), plant composition and coverage tables by community type, and a summary of individual species' response to disturbance (Arno and others 1985). The classification can be used to identify the community type of an individual stand or to predic the kinds of communities that might result after alternative silvicultural treatments.

The classification primarily provides qualitative information to the land manager in the form of a conceptual model composed of community type names and descriptions.

EMPIRICAL MODEL

An empirical computer model was constructed from the successional classification to improve its use as a predictive tool in land management. This computer model, called FORSUM (a FORest SUccessio Model), predicts changes in canopy cover for 74 plant species in the four habitat types listed in table 1 (Keane 1987). FORSUM uses various site ar vegetation characteristics of a predisturbance stand, along with a chosen treatment and intensit to predict species cover from year 5 to year 300 after disturbance. The model produces both graph and tabular output.

KEY TO SUCCESSIONAL COMMUNITY TYPES WITHIN A HABITAT TYPE PHASE

Instructions: Select most appropriate pathway number for the stand in questio through use of the undergrowth key below. Stop at the first requirement that fits.

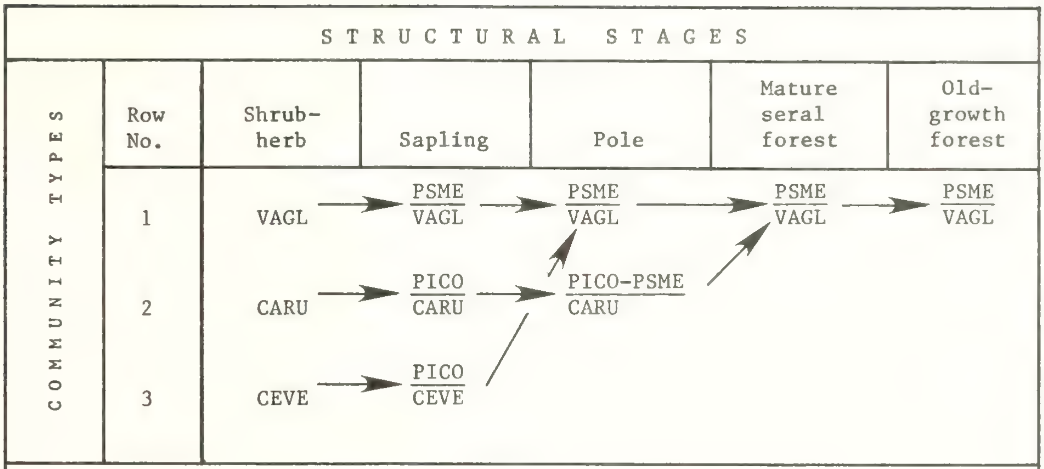
Requirement Pathway numbe

a. Ceanothus velutinus (CEVE) >5% canopy cover . . . .

b. Calamagrostis rubescens (CARU) or Carex geyeri (CAGE) or their combined coverages >25% . . . .

c. Vaccinium globulare (VAGL) >5% canopy cover . . . .

Figure 4--An example successional pathway key in the successional classification.



STAND CHARACTERISTICS

	Shrub-herb	Sapling	Pole	Mature seral forest	Old-growth forest
Tree canopy cover (percent)	0-15	15-90	50-90	50-80	50-70
d.b.h. of dominant trees (inches)	0-1	2-5	6-10	11-15	16-25
Basal area (ft^2/acre)	0-1	2-100	100-250	100-250	150-250
Age (yr)	5-15	15-30	30-100	100-200	200-300

Figure 5--Example of the final classification complete with stand characteristic definitions and pathway keys.

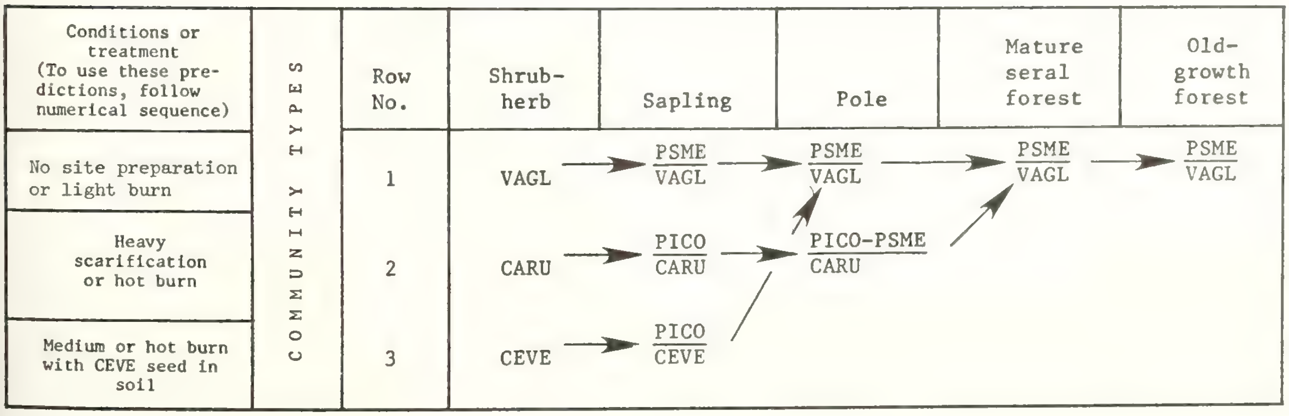

Conditions or treatment (To use these predictions, follow numerical sequence)
No site preparation or light burn
Heavy scarification or hot burn
Medium or hot burn with CEVE seed in soil
COMMUNITY TYPES
Row No.
Shrub-herb
Sapling
Pole
Mature seral forest
Old-growth forest
1
VAGL
PSME/VAGL
PSME/VAGL
PSME/VAGL
PSME/VAGL
2
CARU
PICO/CARU
PICO-PSME/CARU
3
CEVE
PICO/CEVE

Figure 6--Example of the integration of treatment type and severity to successional pathway origin. Conditions and treatment box is shown on the left of the diagram. For example, the CEVE community type results after a moderate to high severity broadcast burn or wildfire in a stand containing CEVE seeds in the soil.

Model Description

Model Construction--Plant species are established in the model based upon their reproductive and survival strategies, shade tolerance, and life form. The type and severity of treatment can also influence species establishment. For example, *Ceanothus velutinus* (CEVE) produces seeds which remain viable in the soil for long periods of time and germinate only after moderate to severe fires. The model would predict CEVE cover only if the treatment were a broadcast burn or wildfire of moderate to high severity, and only if CEVE seeds were present in the soil. Presence of CEVE seed is determined by evidence of CEVE plants at or near the site in question. Seed sources for some herbaceous and shrub species are assumed to be always present on-site because wind will frequently disperse their seeds over large areas.

Changes in coverages of individual species over succession time are calculated from regression equations for each species. These equations were built by first stratifying all stand data in a habitat type phase or potential vegetation type by successional pathway. A multiple regression analysis was then performed on the stratified data for the most frequent or dominant plant species. For instance, eight possible successional pathways were identified in the PSME/VAGL, XETE habitat type phase. Forty species were selected for modeling in these pathways. Since there is a regression equation for each species and pathway, 320 equations are used to predict species cover in this habitat type phase. Independent variables used in the regression analysis included site characteristics (for example, elevation), stand age, kind and severity of treatment, and predisturbance coverage data. The regression equations were coded and entered into a computer file that is accessed during program execution.

Appropriate regression equations used for predicting canopy cover are selected by computing a potential successional pathway for the postdisturbance stand. Individual plant coverages collected from the site to be disturbed and treatment type and severity to be implemented are used as criteria for selecting the pathway. These criteria are incorporated into FORSUM using a series of program commands.

Model Testing--FORSUM was tested extensively using additional field data collected from the study area (fig. 1). In the test, adjacent mature and postdisturbance stands were sampled using methods defined by Arno and others (1986). The predisturbance plant coverage values and site parameters from the mature stands were used as inputs to the model. Next, FORSUM was used to predict postdisturbance plant coverages. Finally, the sampled postdisturbance coverages in cover classes (Pfister and others 1977) were compared with the FORSUM predictions.

Testing results, reported in percent correct, showed the model averaged 74 percent accuracy in the four habitat types. Overall accuracy ranged from 69 percent to 78 percent for 68 sites. However, the model averaged 87 percent accuracy within (+ or -) one cover class (Keane 1987). For many aspects of land management planning a high degree of accuracy for species coverages is not essential. When the two smallest cover classes (T= 0-1% coverage and 1= 1-5% coverage) in FORSUM were combined the accuracy was 85 percent. Succession following clearcutting and broadcast burning or mechanical scarification treatments is more accurately predicted than wildfire or clearcutting with no site preparation (79% as compared to 71%). Tree coverages are more difficult to predict (65% accurate) as compared to undergrowth species (82% accurate).

Correctly identifying successional pathway is a sensitive or critical procedure in FORSUM. If the pathway is misidentified, the wrong regression equations are used to predict cover. However, during model testing the successional pathway was never misidentified. The regression equations are the foundation of the model and will need refinement as additional data become available.

Model Discussion

Model Use--Input data for FORSUM are entered using a "user-friendly" interactive data entry routine. Users can choose from two skill levels for entering input data -- "novice" or "experienced". The user then can select any one of the four treatments in table 2 and implement the treatment at one of the three severities. Input data are typically plant coverage values and site parameters collected from a mature stand that the user wishes to study. The user can project successional cover up to approximately 300 years depending on habitat type phase. FORSUM presents cover predictions in tabular and graphic form and output can be printed on the line printer and/or computer terminal.

Model Access--FORSUM is currently being managed by the Ecosystem Management Program of the USDA Fores Service Northern Region in Missoula, Montana. The computer program, written in the FORTRAN 77 programming language, is operable on the Data General MV series minicomputers, and also on the UNIVAC mainframe in Fort Collins, Colorado. The model has been linked to several vegetation data base management systems to simplify input data entry and allow easy access to vegetation information for a potential stand to be input into FORSUM.

Model Future--FORSUM was designed so that additional habitat types can be implemented with minimal effort. Although development of the species-specific regression equations is data intensive (requiring time for vegetation sampling and community analysis), regression analysis can b accomplished fairly easily. Development of the regression equations for the two phases of the subalpine fir/beargrass habitat type took one analyst approximately 5 weeks working full time. However, analysis can become more difficult as species diversity increases within a habitat type phase.

The Northern Region's Ecosystem Management Program now maintains FORSUM and intends to expand it to cover several new habitat types. Those habitat types scheduled to be added to FORSUM and for which some successional data have been collected include PSME/SYAL (Douglas-fir/snowberry), PSME/CARU (Douglas-fir/pinegrass), PSME/LIBO (Douglas-fir/twinflower), and ABGR/ASCA (grand fir/wild ginger). Others which have been selected but not sampled as yet are ABLA/CLUN (subalpine fir/queencup beadlily), THPL/CLUN (western redcedar/queencup beadlily), and TSHE/CLUN (western hemlock/queencup beadlily). FORSUM has been linked to the ECODATA data base management system for efficient program execution. The Ecosystem Management Program is also in the process of generating guidelines for the development of the regression equations needed in FORSUM.

Additional silvicultural treatments and vegetation variables will also be included in FORSUM. FORSUM will soon be able to predict species coverages after partial cuttings (shelterwood cuttings for example) and prescribed burns. And, in addition to plant coverages, predictions of average shrub height, tree density by species, and exposed mineral soil as a percentage of total area will be generated from FORSUM.

Model Implications--There are many potential uses for FORSUM. Foresters might use it to predict possible vegetational coverages that may compete with planted or natural tree regeneration. Wildlife and range specialists might use FORSUM to compare the effect of alternative treatments on forage and browse species. Hydrologists might use it to decide if a certain treatment will promote the growth of species important for preventing excess soil erosion. Other potential uses include updating vegetation information in GIS (Geographic Information Systems) and demonstrating successional dynamics.

SUMMARY

The successional classification system of Arno and others (1985) provides land managers a means of classifying seral plant communities within a habitat type. The classification can also indicate the position of a community along a succession gradient. This allows the manager to reconstruct the successional history, and more importantly, to predict the successional future of a forest stand. In addition, the classification can be used as a qualitative tool to assess the impacts on the vegetation of various silvicultural treatments or wildfire.

The succession computer model FORSUM improves the predictive ability of the classification by quantifying changes in successional coverage of plant species as a function of treatment type and severity, predisturbance plant composition, and site factors. Using this model, the land manager can project successional shifts in species cover as a consequence of management action. FORSUM is widely available for use and it may soon be expanded to cover additional habitat types.

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REFERENCES

Arno, Stephen F. 1981. Classifying forest succession on four habitat types in western Montana. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest; 1981 March 26; Corvallis, OR.; Oregon State University; 1981: 54-62.

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Sevice, Intermountain Forest and Range Experiment Station. 74 p.

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1986. Characterizing succession within a forest habitat type -- An approach designed for resource managers. Res. Note INT-357. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Cattelino, Peter J.; Noble, Ian R.; Slatyer, R.O.; Kessell, Stephen R. 1979. Predicting the multiple pathways of plant succession. Environmental Management 3(1): 41-50.

Cholewa, A.F.; Johnson, F.D. 1983. Secondary succession in the Pseudotsuga menziesii/Physocarpus malvaceus association. Northwest Science 57: 273-282.

Fischer, William C.; Bradley, Ann F. 1987. Fire ecology of western Montana. Gen. Tech. Rep. INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 95 p.

Fischer, William C.; Kessell, Stephen R. 1981. Predicting postfire plant succession for fire management planning. Gen. Tech. Rep. INT-94. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Gauch, Hugh. 1982. Multivariate analysis in community ecology. Cornell University, Ithaca, New York: Cambridge Studies and Ecology. 298 p.

Keane, Robert E. 1984. Predicting successional plant composition on a Pseudotsuga menziesii/Physocarpus malvaceus habitat type in western Montana. Missoula, MT: University of Montana. 220 p. Thesis.

Keane, Robert E. 1987. Forest succession in western Montana -- A computer model designed for resource managers. Res. Note INT-376. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Pfister, Robert D.; Arno, Stephen F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science 26(1):52-70.

Pfister, Robert D.; Kovalchik, B.; Arno, Stephen F.; Presby, R. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Stickney, Peter F. 1980. Data base for post fire succession, first 6 to 9 years, in Montana larch-fir forests. Gen. Tech. Rep. INT-62. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

Zamora, B. A. 1975. Secondary succession on broadcast-burned clearcuts of the Abies grandis-Pachistima myrsinites habitat type in north-central Idaho. Pullman, WA: Washington State University. 117 p. Ph.D dissertation.

PYRAMID MODELS FOR SUCCESSION CLASSIFICATION

Robert Steele

ABSTRACT: A concept for classifying seral vegetation using indicator species is discussed. Classification and studies of seral vegetation in six habitat types have resulted in some important implications for land managers. Shortcomings of this approach are also noted.

INTRODUCTION

Over the past two decades, habitat type classifications based on potential vegetation (associations) have been developed over much of the western U.S. This recognition of environment through vegetation has fostered an awareness of vegetation diversity, especially among resource managers. Land managers now recognize the need to foresee the changes in vegetation that may result from management activities. But to identify, study, and communicate these changes some form of classification is needed. Habitat type classifications focus on environmental differences affecting potential vegetation. They provide a logical framework for studying succession and occasionally infer successional relationships but offer no classification of seral vegetation.

To classify seral vegetation, I explored several approaches and eventually chose a system (Steele 1984) that uses Hironaka's "cone model" concept of succession (Huschle and Hironaka 1980). The cone model concept was most appealing because it allows one to develop both a systematic and natural classification system. A systematic approach is useful because it reduces subjectivity in classification design and anyone who understands the system can modify and extend the classification to new areas. Natural classification, as opposed to technical ones designed for a specific use, tends to maximize application and prediction capabilities. Habitat types are an example of natural classification and as their originators R. and J. Daubenmire (1968) pointed out, the most natural system is "one that allows the most predictions about a unit from a mere knowledge of its position in the system." Natural classifications are, of course, artificial in the sense of being created by humans. They seldom suit any one purpose ideally but are well suited for multipurpose application.

THE PYRAMID MODEL CONCEPT

Pyramid classification models reflect an elaboration of the cone-shaped succession model (Huschle and Hironaka 1980). The classifications are systematic because the same principles are always applied. The approach is natural because the plant species provide classification parameters through their seral characteristics. For example, consider the tree layer in a given habitat type. (Tree, shrub, and herbaceous layers are treated separately because disturbances such as grazing or logging may affect only one layer and these layers often involve different rates of succession.) In this example, the tree layer contains Abies grandis, Pseudotsuga menziesii, and Pinus ponderosa; each species is "well represented," which is arbitrarily defined as canopy cover of at least 5 percent. This would be an Abies grandis habitat type and only these three tree species would be capable of becoming well represented. From ecological knowledge of these species, derived mainly through field observation, we can diagram their relative successional amplitudes (fig. 1). Pinus ponderosa has the least amplitude because it can be replaced successionally by both Pseudotsuga and Abies. Pseudotsuga can be replaced by Abies but not by Pinus. Although this entire sequence may not happen following each disturbance on a given site, the relative amplitudes have been established for classification purposes.

From a natural classification standpoint, these relative amplitudes have segmented the time gradient on a successional scale and each species serves as an indicator of a particular segment. For classification purposes, the best indicator species is the one that is well represented and has the least successional amplitude (for example, PIPO in fig. 1). Once the time gradient is segmented in this fashion we complete the classification by linking each seral indicator species with the possible dominant species (most canopy cover) for that layer (fig. 2). The result is a series of binomial taxonomic units called layer types (fig. 3) each of which reflects a certain temporal-structural condition. The first element of the binomial is the seral indicator species, the second element is the dominant species. Each group of layer types having the same seral indicator is called a layer group.

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Robert Steele is Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Boise, ID.

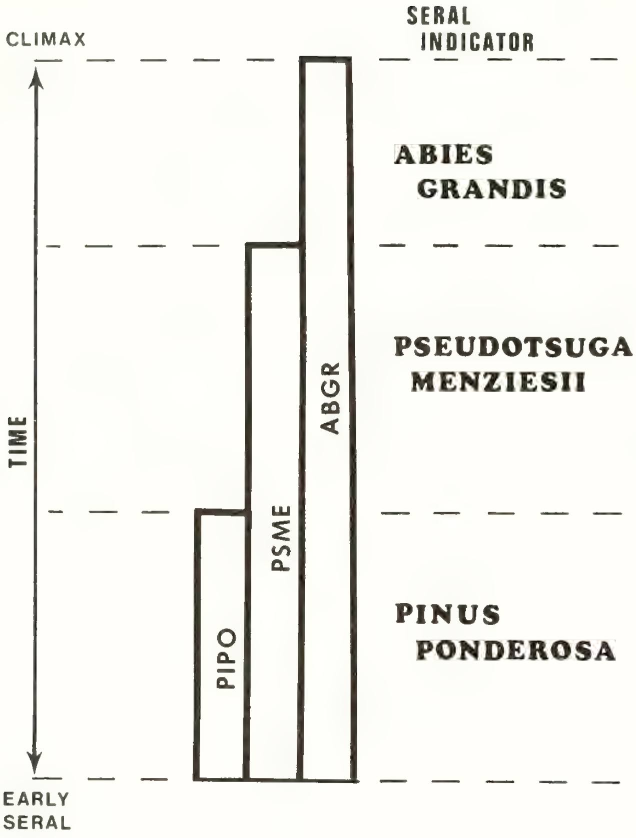

Figure 1--Example of relative successional amplitudes of tree species in a given habitat type.

This basic approach is used in the shrub and herbaceous layers but the tree layer progresses through obvious size classes of development such as sapling (0.1-4 inches d.b.h.), pole (4-12 in), mature (12-18 in), and old-growth (>18 in). These notations should be added to each tree species after the tree layer type is identified. For consistency, the smallest size class that is well represented should be noted for the seral indicator because it usually reflects the most recent regeneration of that species. For the dominant species, the most prevalent size class should be used. When the seral indicator or the dominant species is well represented on the site but not in any particular size class, the size class with the most coverage should be noted.

APPLICATION

This classification approach has been applied to the tree, shrub, and herbaceous layers of six habitat types in central Idaho (Steele and Geier-Hayes 1984, 1985, 1986, 1987a, 1987b, 1987c). The results show that a workable number of taxonomic units can be maintained in spite of high potential diversity. Many layer types occur across several habitat types and are easily recognized even though they may vary in total species composition. Some layer types resul from only one kind of disturbance. Others can be achieved only through uninterrupted succession. Some of these layer types present special problem for achieving tree regeneration; others facilitat

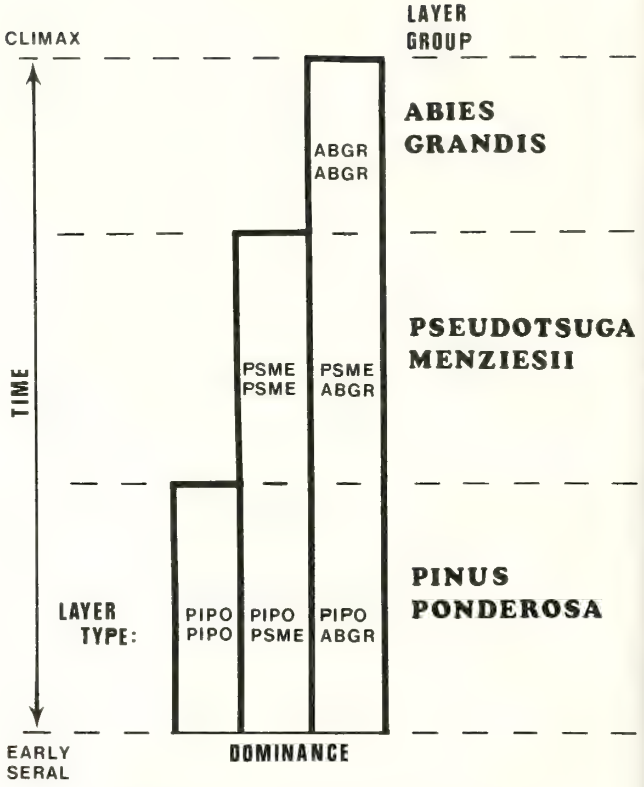

Figure 2--Example of possible seral indicator-dominant species combinations in a given habitat type.

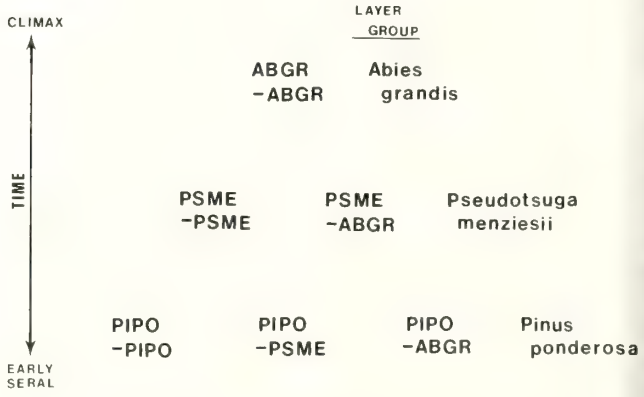

Figure 3--Example of succession classification diagram for the tree layer in a given habitat type.

regeneration. Some herb layer types support high pocket gopher activity, others support very little. Relative forage values for big game and livestock can be derived from species palatability ratings, constancy, and cover and also vary by shrub and herb layer type.

At present, most of the classifications cited above are available only in preliminary draft form. However, annual field training sessions have enabled land managers in central Idaho to use the results and their response has encouraged plans for similar work in other forest habitat types. Much interest has focused on the relationships between site treatment, the resulting shrub and herbaceous layer types, and the long-term effects on tree regeneration. Some interest has been expressed in using this classification approach in other geographic areas and in modeling rates of change within the pyramid models.

Developing these classifications involves many plant species yet relatively few serve as seral indicators. These indicator species appear to be consistent in their successional strategies across habitat types. But their successional role, whether early seral, mid seral, or climax is a function of associated species and varies by habitat type. In general, the successional role of a species shifts toward early seral in more favorable environments and toward climax in the less favorable environments. For instance, Pinus ponderosa may be early seral in Abies grandis habitat types, mid seral in Pseudotsuga habitat types, and climax in Pinus ponderosa habitat types. The extent of these shifts depends on which competitive species occur in the different environments. The implication of this for land managers is that plant species will generally establish more readily where they have major early seral roles than where they have late seral to climax roles. However, early seral species generally require special site preparation and are less apt to maintain their populations without repeated disturbance.

SHORTCOMINGS OF THIS SYSTEM

Like most systems, pyramid classification models have shortcomings. The system is based on species canopy cover and relative successional amplitudes. Canopy cover is not always proportional to canopy volume and total biomass can vary within layer types. Relative successional amplitudes for all seral indicators are not yet known, especially in the herb layer. Considerable field study is needed before pyramid models can be established for all seral vegetation in all habitat types. Existing pyramid models should always be open to further revision. Layer type designations are a function of only two species, seral indicator and dominant. Consequently, there can be high variability in total species composition within a layer type although usually this is not the case. Pyramid models do not predict what the next layer type will be for each stand within a given layer type. They only illustrate the successional possibilities that remain as well as situations no longer possible unless disturbed. For individual stands, however, predicting the next layer type is possible by comparing total species composition of the stand with successional trends outlined in the pyramid models. For example, if a given stand contains a tree canopy cover of 10 percent PIPO, 40 percent PSME, and 20 percent ABGR, it will classify in figure 3 as a PIPO-PSME tree layer type. Once the pine has declined so that it is no longer well represented, the next layer type will most likely be PSME-PSME.

CONCLUSIONS

In spite of their shortcomings, pyramid classification models provide a systematic and natural approach to classifying seral vegetation. They were designed to provide a taxonomic framework for general field use but can be used to identify seral stages in simulation models. They also provide succession prediction capability for individual stands when the species composition is known.

Pyramid models accommodate the somewhat independent nature of succession between the tree, shrub, and herbaceous layers and treat these three successions separately. These models provide for the high potential diversity of early and mid-seral vegetation. Different kinds of disturbances can result in different shrub and herbaceous layer types which, in turn, affect pocket gopher populations and tree establishment. Shrub and herbaceous layer types can also be assigned forage resource values. Perhaps most important, these models provide a common framework for communication of seral plant communities among various resource disciplines.

REFERENCES

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agriculture Experiment Station. 104 p.

Huschle, G.; Hironaka, M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33(3): 179-182.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58(1): 29-39.

Steele, R.; Geier-Hayes, K. 1984. The Douglas-fir/pinegrass habitat type in central Idaho, succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 124 p. Preliminary draft.

Steele, R.; Geier-Hayes, K. 1985. The grand fir/mountain maple habitat type in central Idaho, succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 118 p. Preliminary draft.

Steele, R.; Geier-Hayes, K. 1986. The Douglas-fir/white spirea habitat type in central Idaho: succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 96 p. Preliminary draft.

Steele, R.; Geier-Hayes, K. 1987a. The Douglas-fir/elk sedge habitat type in central Idaho: succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 111 p. Preliminary draft.

Steele, R.; Geier-Hayes, K. 1987b. The Douglas-fir/ninebark habitat type in central Idaho, succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 83 p. Review draft.

Steele, R.; Geier-Hayes, K. 1987c. The grand fir/blue huckleberry habitat type in central Idaho, succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

FORECASTING SECONDARY SUCCESSION WITH THE PROGNOSIS MODEL AND ITS EXTENSIONS

Melinda Moeur and Dennis E. Ferguson

ABSTRACT: The Prognosis Model for Stand Development predicts growth and development of individual trees in forest stands. The Regeneration Establishment and COVER extensions to the Prognosis Model have enhanced its ability to forecast secondary succession by predicting establishment of conifers and development of understory plants following stand disturbance. This paper discusses how secondary succession is predicted, emphasizing the role of habitat types in study design, data analysis, and model construction. Examples are given showing simulations for 40 years following harvest.

INTRODUCTION

The Prognosis Model (Stage 1973; Wykoff and others 1982) is usually thought of as a growth and yield simulator for forest stands. But the Prognosis Model and its extensions, Regeneration Establishment (ESTAB) and COVER, also incorporate successional concepts that enable it to realistically model changes in combinations of trees and understory plants through time. ESTAB predicts conifer regeneration following site disturbance (Ferguson and Crookston 1984). COVER (Moeur 1985) predicts tree canopy cover and biomass, and the probability of occurrence, height, and cover of shrubs, forbs, and grasses in the understory.

Biological characteristics of tree and understory species drive the models. The ecological potential of vegetation on different sites is incorporated into the models through the inclusion of habitat type and variables representing site conditions. An important part of our approach is that the models are derived from a large sample representing a wide range of site characteristics, stand structure, and silvicultural practices on the processes of vegetation change. Data to develop the models were measured on stands selected in a random, unbiased manner, covering a fairly complete range of stand and site conditions and regeneration activities likely to be encountered in application.

Using the combined Prognosis, ESTAB, and COVER models, tree and understory development may be simulated from rotation to rotation. This paper focuses on projections for the first 40 years following harvest, showing the use of habitat types in modeling secondary succession.

The Prognosis Model

The Prognosis Model simulates stand development by predicting growth and mortality of individual trees sampled from an inventory. For each growth projection cycle (normally 10 years), the model predicts diameter and height growth, change in crown ratio, and mortality for each tree in the inventory (Wykoff and others 1982). In the Inland Empire version of Prognosis, growth relationships are included for 11 commercial conifer species. If harvest and site preparation activities are simulated, postharvest stand conditions stored by the Prognosis Model are passed to ESTAB and COVER to make predictions of secondary succession. Subsequent accretion, mortality, and user-implemented management prescriptions are handled by the main Prognosis Model.

The ESTAB Model

ESTAB predicts initial attributes of regenerating stands as they would appear if examined between 3 and 20 years after harvest and site preparation. Predictions include the probability of stocking for 1/300-acre plots, total trees per acre, species composition, identification of best trees, and heights of established seedlings.

Version 1.0 of ESTAB covers the grand fir-cedar-hemlock (Abies grandis-Thuja plicata-Tsuga heterophylla) ecosystem centered in northern Idaho (Ferguson and others 1986). Additional sampling has been conducted in Montana (Carlson and others 1982) and in Idaho (Ferguson and Stage 1982a) to include other vegetation types and geographic areas. These data are being used to extend ESTAB to Pseudotsuga menziesii and Abies lasiocarpa series and will be available in version 2.0.

In each study mentioned above, a stratified random sample was used to select operationally harvested stands 3 to 20 years old. Candidate stands were classified by habitat type, site preparation, regeneration method, and geographic location. Four or five stands within each combination were randomly chosen for sampling. Elevation, geographic location, dates of harvest, site preparation, and planting were recorded for each stand. Transect lines were drawn on aerial photographs and field crews sampled about 25 1/300-acre circular plots per stand along the transects. Information recorded by plot included habitat type, slope, aspect, type of site disturbance, topographic position, and overstory density by species. Conifer regeneration was counted by species, and

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elinda Moeur and Dennis E. Ferguson are Research oresters, Intermountain Research Station, Forest ervice, U.S. Department of Agriculture, Moscow, ID.

height and age were subsampled on best trees on the plot. The total sample from which version 2.0 of ESTAB is being developed includes more than 12,000 1/300-acre plots from 537 stands.

The COVER Model

Two submodels within COVER predict the structure of tree crowns and understory vegetation. The CANOPY submodel predicts crown dimensions of individual trees, canopy closure, and foliage biomass of all conifers in the stand. Understory development is projected by the SHRUBS submodel for the initial 40 years following stand disturbance. Probability of occurrence on 1/300-acre plots, height, and percent cover are projected individually for each of 31 species or species groups common to northern Rocky Mountain forests.

Data used to develop the SHRUBS submodel were collected concurrently with the regeneration establishment studies by Ferguson and others (1986) and Ferguson and Stage (1982a) plus data from a regeneration development study (Deitschman and others 1974; Ferguson and Stage 1982b). The development study provided data for predicting 5-year periodic height growth of conifer regeneration in the same geographic areas as the regeneration establishment studies. These stands were selected to represent combinations of habitat type, regeneration method, geographic location, tree size, and tree species.

On both the regeneration establishment and development plots, average height and percentage of plot coverage were recorded by species for shrubs, forbs, ferns, and grasses on 1/300-acre plots, and density of the conifer overstory was measured on a variable radius plot. Data from all studies yielded 32,000 observations on 10,500 plots in over 500 stands.

HOW HABITAT TYPES ARE USED

Habitat types are the framework within which we have modeled conifer establishment and understory species occurrence and development. Habitat type incorporates many site characteristics and acts as an indicator of ecological potential in the models. In ESTAB and SHRUBS, habitat type accounts for much of the explainable variation in the data. The inclusion of other variables in the equations--slope, aspect, elevation, stand history, and overstory characteristics--improves predictions.

In ESTAB, habitat type is the second most important independent variable used to predict the probability of stocking on 1/300-acre plots (Ferguson and others 1986). The most important variable is time since disturbance, with 10 other variables being less important than habitat type.

In our secondary succession studies, habitat type, geographic area, site disturbance, and regeneration method were used to categorize stands so that combinations of events would be included in the sample. This stratification ensured coverage of most ecological conditions likely to be encountered in forest management. Equally important is the use of habitat types in analyzing data and constructing models. Three examples follow.

Habitat Type Groups

Habitat types for version 1.0 of ESTAB used the classification system of Daubenmire and Daubenmire (1968). Version 2.0 uses systems of Pfister and others (1977) for Montana, Cooper and others (1987) for northern Idaho, and Steele and others (1981) for central Idaho.

For version 2.0 of ESTAB, habitat types were combined into 16 groups (table 1). Habitat types with nonsignificant differences between means for three variables (percentage of stocked plots, trees per stocked plot, and species per stocked plot) using Duncan's multiple range test (p=0.05) were combined within series. These variables correspond to important steps in ESTAB. Because the analysis did not account for differences in other site factors, the groupings were considered preliminary and were reviewed by area ecologists. Habitat types with limited data were combined with ecologically similar types.

In the SHRUBS submodel, 34 recorded habitat types were collapsed into groups to create two new variables--five habitat type overstory series representing climax tree species and six groups representing understory union (table 2). Analysis of covariance with time since disturbance as the covariate was used to reduce original understory unions to six classes (Laursen 1984). Temperature-moisture regime and number of shrub canopies and species supported in each union were used subjectively to make final adjustments in each grouping. Understory unions fell into one class of grass- and sedge-dominated communities, two classes representing low and mid shrub-dominated communities, and three classes typified by a high degree of potential structural diversity (tall, medium, and low species combined).

Species Occurrence

Species occurrence in ESTAB is very dependent on habitat type. Habitat types or groups are used as class (dummy) variables in regression equations so that each habitat type has a unique probability for the species being modeled. Ecological bar charts developed by Daubenmire (1966), shown in figure 1, detail the occurrence of species by climax series.

Species occurrences are used to partition data into logical units for analysis in ESTAB. For example, to predict the probability of occurrence of grand fir, only four series are analyzed--Abies grandis, Thuja plicata, Tsuga heterophylla, and Abies lasiocarpa. Plots falling in the Pinus ponderosa or Pseudotsuga menziesii series are excluded since the probability of grand fir occurring on such plots is nil. Even within a series, some habitat types do not support species found elsewhere in the series. These types can also be excluded from the analysis.

Table 1--Habitat type group for predicting conifer regeneration in the Regeneration Establishment Model. See table 3 for explanation of species codes

Habitat type group	Number of plots	Percent stocking	Trees/ stocked plot	Species/ stocked plot
1 PSME/VAGL,LIBO,VACA	296	59.1	3.49	1.36
2 PSME/CARU,CAGE,FEID, AGSP	417	29.5	2.99	1.21
3 PSME/PHMA,ACGL	832	25.4	2.31	1.14
4 PSME/SYAL,SPBE,SYOR, ARUV,ARCO,BERE	887	27.8	2.35	1.13
5 ABGR/LIBO,CLUN-XETE	273	79.5	5.06	1.81
6 ABGR/XETE,VAGL,COOC, VACA	451	45.7	3.22	1.48
7 ABGR/CLUN (except CLUN-XETE)	1,865	51.3	4.36	1.48
8 ABGR/SPBE,ACGL,PHMA, ASCA,SETR	989	37.3	2.53	1.28
9 THPL/all	2,180	61.1	9.53	1.74
10 TSHE/all	1,387	71.7	10.53	2.05
11 ABLA/VAGL,VASC,VACA	342	63.4	4.73	1.44
12 ABLA/XETE,LIBO	675	58.2	4.04	1.56
13 ABLA/CLUN,GATR	680	54.0	6.53	1.65
14 ABLA/CAGE,CARU,ACGL, SPBE	228	36.8	2.79	1.23
15 ABLA/MEFE, ALSI, and TSME/CLUN,XETE,MEFE, STAM	460	66.1	6.78	1.66
16 ABLA/CACA,STAM,LUHI	166	35.5	3.81	1.36
	12,128			

Table 2--Habitat type group used to predict probability of occurrence, height, and cover of understory species in the SHRUBS model. See table 3 for explanation of species codes

Overstory series groups	Number of plots
1 PSME/all	1,024
2 ABGR/all	3,311
3 THPL/all	2,649
4 TSHE/CLUN	2,041
5 ABLA/all and TSME/XETE	1,493
	10,518

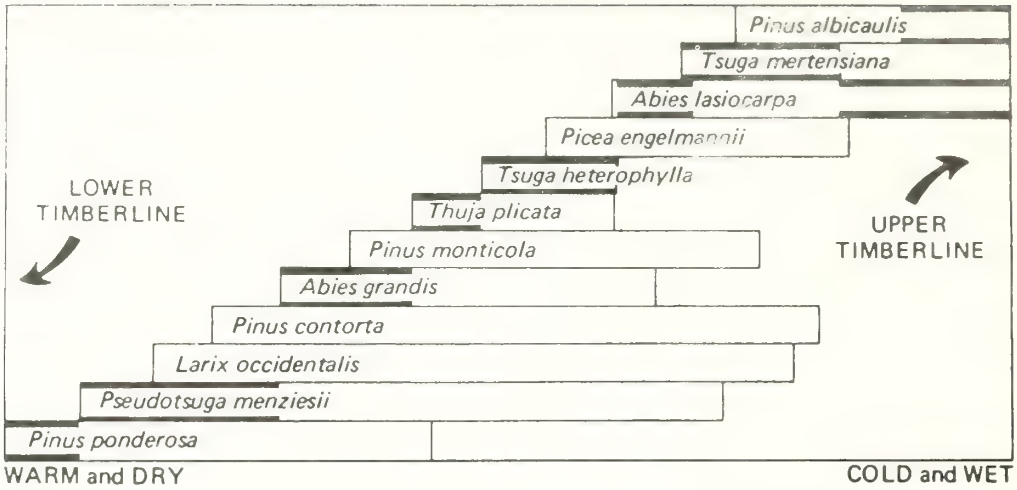
Understory union groups	Number of plots
1 ABGR/CLUN,COOC,LIBO,XETE; TSME/XETE; ABLA/XETE,STAM,LUHI,VASC	2,743
2 PSME/PHMA,ACGL; ABGR/ACGL,VAGL; ABLA/ACGL,MEFE,VAGL,VAGL-VASC	1,332
3 THPL/all	2,649
4 PSME/SYAL,SYOR,SPBE,BERE; ABGR/SPBE; ABLA/SPBE	781
5 ABLA/CLUN; TSHE/CLUN	2,702
6 PSME/CARU,FEID,AGSP,CAGE; ABLA/CAGE, CACA	311
	10,518

Table 3--Abbreviations for scientific names

Code	Scientific name
ABGR	*Abies grandis*
ABLA	*Abies lasiocarpa*
ACGL	*Acer glabrum*
AGSP	*Agropyron spicatum*
ALSI	*Alnus sinuata*
ARCO	*Arnica cordifolia*
ARUV	*Arctostaphylos uva-ursi*
ASCA	*Asarum caudatum*
BERE	*Berberis repens*
CACA	*Calamagrostis canadensis*
CAGE	*Carex geyeri*
CARU	*Calamagrostis rubescens*
CLUN	*Clintonia uniflora*
COOC	*Coptis occidentalis*
FEID	*Festuca idahoensis*
GATR	*Galium triflorum*
LIBO	*Linnaea borealis*
LUHI	*Luzula hitchcockii*
MEFE	*Menziesia ferruginea*
PHMA	*Physocarpus malvaceus*
PSME	*Pseudotsuga menziesii*
SETR	*Senecio triangularis*
SPBE	*Spiraea betulifolia*
STAM	*Streptopus amplexifolius*
SYAL	*Symphoricarpos albus*
SYOR	*Symphoricarpos oreophilus*
THPL	*Thuja plicata*
TSHE	*Tsuga heterophylla*
TSME	*Tsuga mertensiana*
VACA	*Vaccinium caespitosum*
VAGL	*Vaccinium globulare*
VASC	*Vaccinium scoparium*
XETE	*Xerophyllum tenax*

In the understory models, probability of occurrence is related more strongly to habitat type than to other variables, representing restrictions in the ecological distribution of the species (Scharosch 1986). As examples, mesic understory species such as *Vaccinium membranaceum* have predicted probability of occurrence close to zero in habitat types having dry, grass-type understory unions, shifting to more consistent occurrence in moister habitat types (fig. 2); predicted occurrence of *Physocarpos malvaceus* is fairly well restricted to the *Pseudotsuga menziesii*/*Physocarpos malvaceus* association; and predicted occurrence of *Symphoricarpos albus* reflects published constancy values (Cooper and others 1987, for example).

Other important understory species' characteristics preserved in the predictions include patterns in early or late successional development, response to type of disturbance, and species' shade tolerance. In general, understory union is also a strong predictor of total shrub cover. Understory union integrates physical site characteristics, the number of understory canopies a site can support, and potential domination by particular species adapted to growth on a given site (Laursen 1984). Understory unions capable of supporting multiple shrub canopies (low, medium, and tall species) predict relatively higher total cover.



Coniferous trees in the area centered on eastern Washington and northern Idaho, arranged vertically to show the usual order in which the species are encountered with increasing altitude. The horizontal bars designate upper and lower limits of the species relative to the climatic gradient. That portion of a species' altitudinal range in which it can maintain a self-reproducing population in the face of intense competition is indicated by the heavy lines.

Figure 1--Ecological bar chart showing species occurrence by overstory series (modified from Daubenmire 1966. Copyright 1966 by the AAAS).

Optimum Aspect

Data can also be partitioned and tested for effects that differ among habitat types. For example, regeneration of Douglas-fir (Pseudotsuga menziesii), a species having a wide ecological amplitude, might differ among climax series. Daubenmire (1976) said "... the Pseudotsuga/Physocarpos forest occurs on steep north-facing slopes at its lowest altitudinal limits, moves onto zonal soils at intermediate elevations, then onto the shallow soils of steep south-facing slopes at its highest limits." It follows that the best aspect for Douglas-fir regeneration might vary with climax series. We were able to test this hypothesis using data collected for version 2.0 of ESTAB.

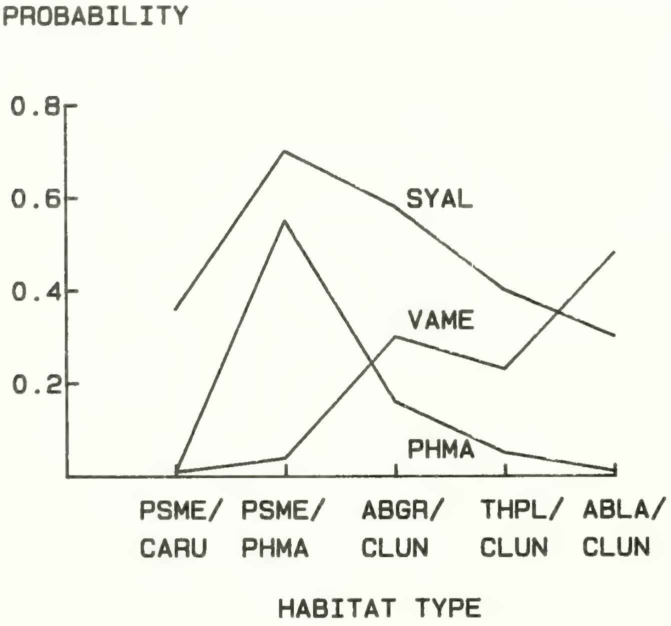


Figure 2--Occurrence of selected shrub species on habitat types as predicted by the SHRUBS model. Variables held constant: 30 percent slope, west aspect, no site preparation, 3,500 feet elevation, and 20 years since harvest. Although habitat types are not continuous, points on the graph have been connected to display trends in species occurrence.

Regression equations for the probability of subsequent Douglas-fir regeneration on stocked plots were developed by climax series--either Pseudotsuga menziesii, Abies grandis, Thuja plicata/Tsuga heterophylla together, or Abies lasiocarpa. Independent variables were slope, aspect, elevation, site preparation, time since disturbance, and residual basal area and species composition.

Results of these regression analyses support Daubenmire's statement. The optimum aspect in our model for Douglas-fir in the Pseudotsuga menziesii series is northerly (fig. 3). Aspects in the Abies grandis and Thuja plicata/Tsuga heterophylla series were nonsignificant (therefore not plotted) and the optimum aspect for Douglas-fir in the Abies lasiocarpa series is southerly. If habitat types were not used to partition the data, optimum aspect would be incorrectly predicted or aspect would have been insignificant and dropped from the equation.

Aspect is also a significant predictor of shrub species' occurrence. Figure 4 shows shrub predictions for Pseudotsuga menziesii/Symphoricarpos albus and Abies lasiocarpa/Menziesia ferruginea habitat types. Symphoricarpos albus and Menziesia ferruginea show opposite patterns in occurrence, with Symphoricarpos highest and Menziesia lowest on south aspects.

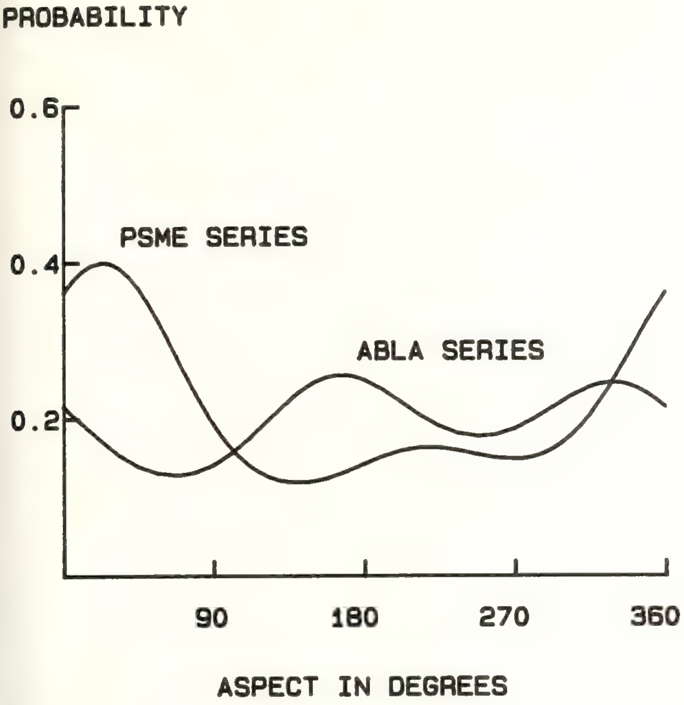


Figure 3--Probability of subsequent Douglas-fir regeneration by aspect for the Pseudotsuga menziesii and Abies lasiocarpa series. Variables held constant: 30 percent slope, no site preparation, 3,500 feet elevation, 20 years since harvest, and no overstory.

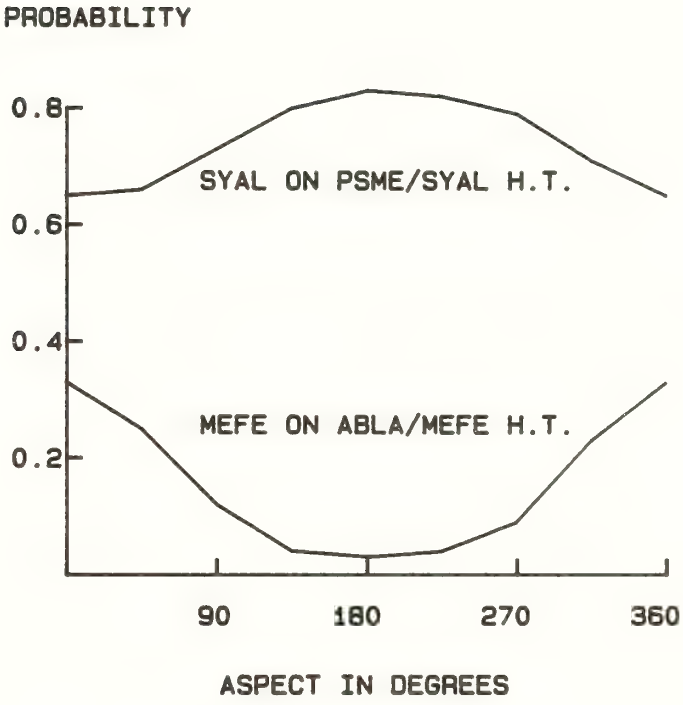


Figure 4--Probability of occurrence by aspect of Symphoricarpos albus on a Pseudotsuga menziesii/Symphoricarpos albus habitat type and Menziesia ferruginea on an Abies lasiocarpa/Menziesia ferruginea habitat type.

Other site variables influence the understory predictions. Greater understory development is predicted at low elevations and moderate to steep slopes. Overstory basal area and time since disturbance affect trends in species' height and cover development, and longevity. They explain more variation later in the successional sequence, reflecting species' sensitivity to overstory development. Type of disturbance influences the predictions by shifting height and cover values up or down reflecting species' adaptations to particular environments (Laursen 1984).

AN EXAMPLE PROJECTION

Four components of Prognosis drive predictions of secondary succession --the COVER and ESTAB extensions, and regeneration height growth and mortality equations in the main Prognosis model. Regeneration height growth equations are given by Wykoff and others (1982) and the mortality model is that of Hamilton (1986). All four components must work in harmony. An example will show results of exercising these models.

Two hypothetical stands were projected. They are similar except for habitat type. One stand is an Abies grandis/Pachistima myrsinites (ABGR/PAMY) habitat type and the other a Tsuga heterophylla/Pachistima myrsinites (TSHE/PAMY) habitat type (Daubenmire and Daubenmire 1968). Other attributes are south aspect, 30 percent slope, 3,500 feet elevation, no residual overstory, no site preparation, and the stands are located on the Clearwater National Forest, ID. Projections were made with version 5.2 of the Prognosis Model.

Projected conifer regeneration in the TSHE/PAMY habitat type is more rapid and the density of trees is greater than in the ABGR/PAMY habitat type (fig. 5). After 20 years, 645 trees are predicted for the TSHE/PAMY stand and 263 for the ABGR/PAMY stand. The number of trees in both stands is low because of the steep, south aspect. Species composition in the ABGR/PAMY stand is mostly grand fir and Douglas-fir. The TSHE/PAMY stand regenerates well to western hemlock and western redcedar which, by definition, do not occur in the ABGR/PAMY habitat type.

Average height of the largest 40 trees per acre is higher for all time intervals in the TSHE/PAMY stand (fig. 6). Canopy closure progresses faster in the TSHE/PAMY stand (fig. 7), due to greater numbers of trees per acre and faster growth rates.

Total shrub cover is greater in the ABGR/PAMY stand (fig. 8). Shrub cover in the TSHE/PAMY stand is less and begins to drop sharply between stand age 30 and 40. This faster decrease is attributable to a faster progression toward canopy closure resulting from more trees per acre and faster growth rates in the TSHE/PAMY stand.

Predicted shrub species composition of the two stands was quite similar. Tall shrubs consisted of Acer glabrum, Amelanchier alnifolia, Ceanothus velutinus, Salix spp., and Cornus stolonifera. Medium shrubs common to both stands were Rubus parviflorus and Vaccinium membranaceum. The ABGR/PAMY stand had a good deal of Symphoricarpos albus while the TSHE/PAMY stand had little. Both stands had the same low shrub species--Pachistima myrsinites, Spiraea betulifolia, and Linnaea borealis.

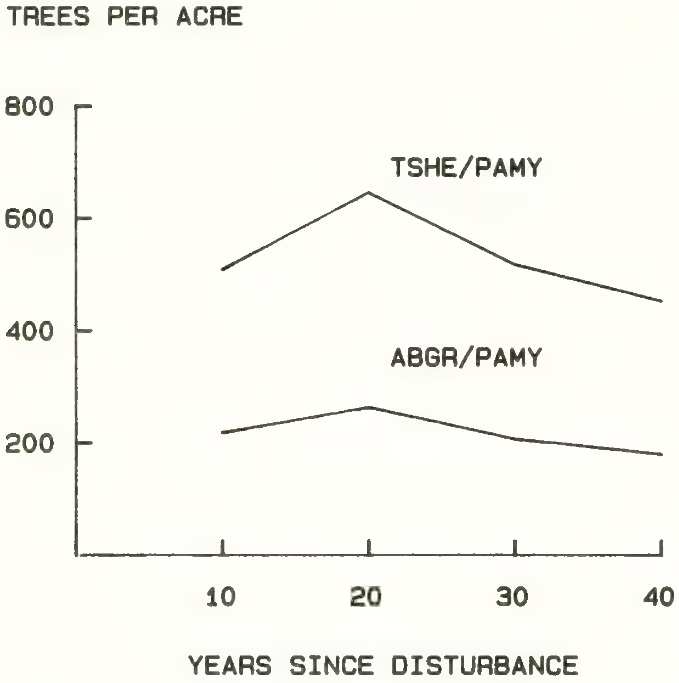


Figure 5--Predicted trees per acre by habitat type.

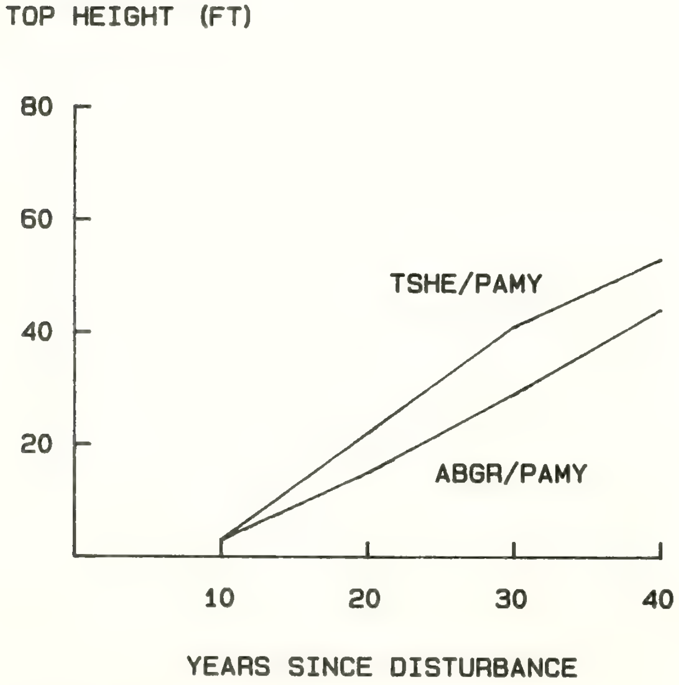


Figure 6--Predicted conifer top height by habitat type.

DISCUSSION

Succession modeling in the COVER and ESTAB models deals with the early, formative years in the life of a stand. Stand dynamics are rapid, setting the

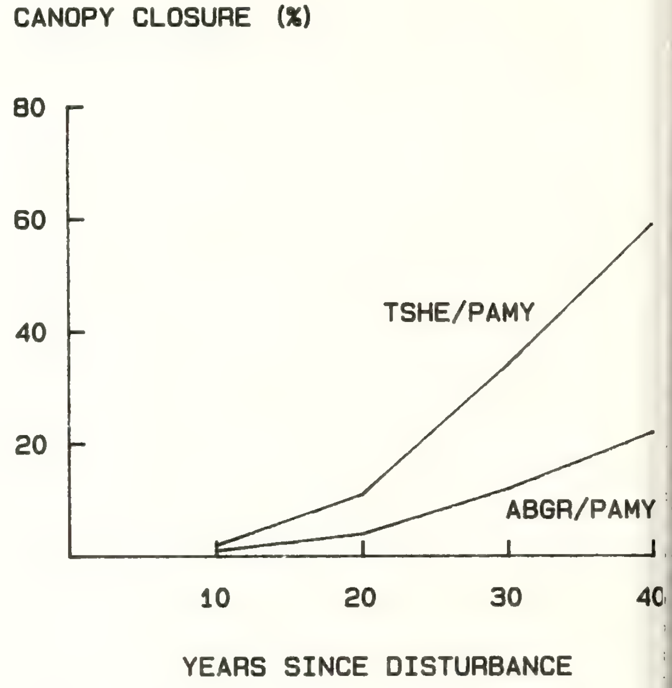


Figure 7.--Predicted conifer canopy closure by habitat type.

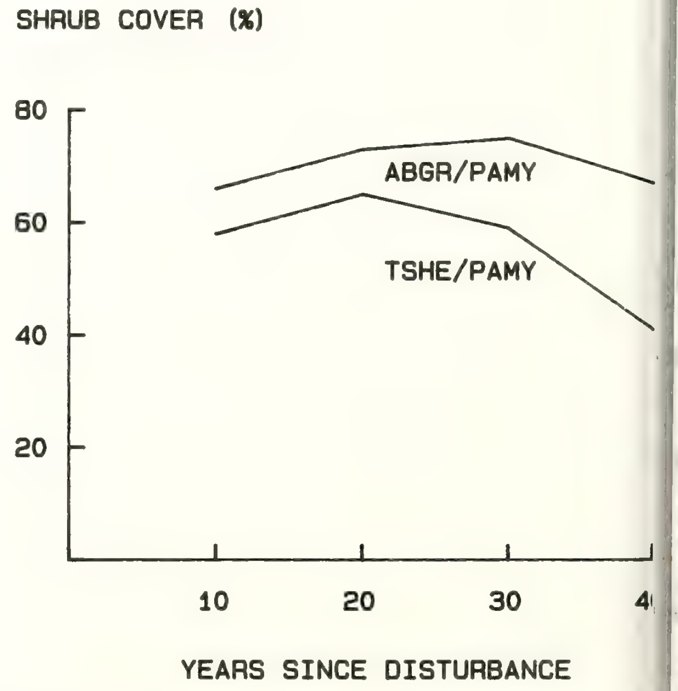


Figure 8--Predicted shrub cover by habitat type.

stage for the remainder of the rotation. Silvicultural prescriptions, beginning with the regeneration method and followed by site preparation, planting, and pest control, are accomplished at this time.

In modeling secondary succession we have chosen to measure and include in the predictive models certain biological and environmental variables that are clearly related to conifer seedling establishment and shrub response to disturbance. The concept behind this is simple: succession, while an extremely variable process, is not a random process. If it were random, the model predictions would be no better than chance. Clearly, habitat types play an important role in representing successional trends in the model.

One unique aspect of COVER and ESTAB is that they incorporate the effects of numerous site and stand history variables--habitat type, aspect, slope, elevation, overstory density, and disturbance history --which have not often been considered in other studies. The resulting equations provide generally well-behaved, biologically reasonable predictions that explain much of the inherent variability in post-disturbance communities.

We believe combining theoretical concepts of species ecologies with a statistically based relationship drawn from a large sample is a good way to represent successional trends over a wide range of site and management conditions, especially in the context of a stand simulation model. For best inferences of succession on a particular site, this approach combined with pre-disturbance sampling of initial floristics, may give excellent results.

REFERENCES

Carlson, C. E.; Theroux, L. J.; McCaughey, W. W. 1982. The influence of silvicultural practices on the susceptibility and vulnerability of northern Rocky Mountain forests to the western spruce budworm: comprehensive progress report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 55 p.

Cooper, S. V.; Neiman, K. E.; Steele, R.; Roberts, D. W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Daubenmire, R. 1966. Vegetation: identification of typal communities. Science. 151: 291-298.

Daubenmire, R. 1976. The use of vegetation in assessing the productivity of forest lands. Botanical Review. 42: 115-143.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, Washington Agricultural Experiment Station. 104 p.

Deitschman, G. H.; Boyd, R. J.; Foiles, M. W. 1974. Study plan: regeneration development and thinning effects phases of the cedar-hemlock ecosystem stand modeling study, 1974. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 25 p. plus supplement.

Ferguson, D. E.; Crookston, N. L. 1984. User's guide to the Regeneration Establishment Model--a Prognosis Model extension. Gen. Tech. Rep. INT-161. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Ferguson, D. E.; Stage, A. R. 1982a. The effects of spruce budworm on regeneration success in Idaho's forest ecosystems: Progress report. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 25 p.

Ferguson, D. E.; Stage, A. R. 1982b. Impact of defoliation by spruce budworm on growth and development of young timber stands in Idaho: Progress report. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Ferguson, D. E.; Stage, A. R.; Boyd, R. J. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. Forest Science Monograph 26. 41 p.

Hamilton, D. A., Jr. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. Forest Science. 32: 989-1000.

Laursen, S. B. 1984. Predicting shrub community composition and structure following management disturbance in forest ecosystems of the Intermountain West. Moscow, ID: University of Idaho. 261 p. Dissertation.

Moeur, M. 1985. COVER: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model. Gen. Tech. Rep. INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 49 p.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Scharosch, S. 1986. Predicting probability of occurrence for selected shrub species in the understory of north and central Idaho forests. Moscow, ID: University of Idaho. 145 p. Thesis.

Stage, A. R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Wykoff, W. R.; Crookston, N. L.; Stage, A. R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

SUCCESSION MODELING AND WILDLIFE HABITAT MANAGEMENT

L. Jack Lyon

ABSTRACT: Successional theory has had little impact on the practice of wildlife management except possibly as a means of predicting success in habitat manipulation. In recent years, however, evaluating habitat quality and predicting the future have become important parts of planning. Using computers, we have constructed wildlife habitat models to examine and evaluate forest environments and forest succession models to predict growth and structure of plant communities. We have paid surprisingly little attention to the quality of these models. Wildlife models produce scalar values rather than numbers, depend on concepts of sometimes questionable validity, are limited by hidden or unstated assumptions, and stray with some regularity from biologically meaningful assessment. Succession models lack a strong basic concept, are too general or too specific, and often provide the wrong kind of information. We probably should remember that predictions of changes in wildlife populations over time are only as good as the habitat models and succession models used to make predictions.

INTRODUCTION

Succession is "...one of the oldest shared research commitments in ecology..." (Johnson 1979). Succession science, if such a science exists, has a large body of theory dating back to 1859, but management applications in some fields still seem to be floundering. Applications to wildlife management, in particular, have evaded development beyond what many biologists consider completely obvious wildlife management theory. Wildlife habitats change over time, and as a consequence, so do wildlife populations. When habitat changes occur as natural events, we call them succession. When the changes result from management action, we like to call it habitat manipulation. Either way, positive and predictable benefits for wildlife are as often the result of serendipity as of good intentions. We recognize that habitat changes are occurring, we may even cause those changes, but no one quite seems to know what to do about them.

There are probably several good reasons succession theory has not become an integral part of wildlife management. It is difficult, for example, to deal with the concept of succession when even the experts in the field cannot decide what it is, or how to describe it. Today, in this session, you have heard four different versions of the way succession can be described. Even a brief review of the historically important literature will reveal the theoretical disagreements of Clements and Gleason and the quantum changes in viewpoint represented in the writings of Odum, and more recently West, Shugart, and Botkin (West and others 1981). However, the fact that the causal relationships of succession have not been described with scientific rigor should not be considered limiting. Quite a lot of wildlife management lacks scientific rigor.

A secondary reason succession theory is not integral to wildlife management involves the view that vegetation science is peripheral to everyday wildlife management. For many game species, management consists of annual surveys, hunting season reports, and even wishful thinking to provide information on which decisions can be made. The required data collection and decisions are made in a short time frame, uninfluenced by succession.

Planned habitat manipulation brings wildlife management and succession into a slightly closer relationship, but the manager may still consider the growth of vegetation a peripheral concern. Blasting an open water pond in a cattail marsh clearly provides more action than watching the grass grow on a burned winter range. When measurable responses in numbers of animals take more than a few years, the level of excitement does not reach great peaks.

Evaluation of wildlife habitats probably represents the closest relationship between management and succession because successional communities often provide the categories of analysis. Again, however, this wildlife management task is usually done on a short time frame, uninfluenced by successional changes. Predictions of successional change should be a standard part of the evaluation analysis, but such predictions are very rarely completed.

In recent years, the importance of succession to changes in wildlife habitats and wildlife populations has become more widely recognized because so much effort is going into planning. The development of National Forest plans, in particular, has emphasized both short-term and

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L. Jack Lyon is Wildlife Habitat Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

long-term influences of timber harvest on the forest environment and on forest wildlife populations. Wildlife managers are still uncertain about the future, but at least an action framework has been established, and some recent developments represent exciting new theory.

The current framework for integrating successional knowledge into wildlife habitat management involves two basic concepts: (1) that the quality of existing and future wildlife habitats can be evaluated, and (2) that successional information is adequate to allow prediction of form and structure in future wildlife habitats. In the remainder of this paper I consider the thesis that neither of these concepts currently provides a foundation worthy of the massive structure being built.

ASSESSING HABITAT QUALITY

Aldo Leopold (1933) described "game range," for any wildlife species, as a place where food and cover are found in appropriate juxtaposition. Today such places are called "wildlife habitats" rather than game ranges, but in over 50 years there has been no particular improvement in the definition. And, while our ability to measure and describe the characteristics of wildlife habitats appears to have become more sophisticated in those 50 years, it is not clear that the results are any more accurate. We have taken computers and created a complex system of models that claims to evaluate habitat quality, but our answers take the form of esoteric and parochial value scales of habitat quality with only presumptive relationships to actual or potential animal numbers and population characteristics.

Is output of real numbers an impossible goal? If we examine some recent wildlife habitat research and the direction current research seems to be heading, it does not appear impossible. Only 4 years ago there was enough interest in wildlife habitat modeling to justify the international symposium, Wildlife 2000, and the compilation of nearly 80 papers (Verner and others 1986) describing recent work in this area. It was a disappointment that a substantial proportion of those papers demonstrated the failure of models to yield accurate predictions. At the same time, the printed proceedings provide many incentives for the development of better models. One of the most pressing is that models will be used even when we recognize that such use "...is not controlled by scientific veracity, though one would like to have the most accurate models affordable" (Salwasser 1986: 423).

Wildlife Habitat Models

Models intended to describe wildlife habitat have taken a wide variety of forms, from simple linear and curvilinear regression equations to complex multiple regressions and even more complex modifications involving geographic information systems (GIS). Berry (1986) provided a brief overview of modeling for the Wildlife 2000 Symposium, and left little doubt that models and modeling systems proliferate, and create new acronyms, at a much higher rate than tests of model validity.

The Fish and Wildlife Service, the Forest Service, and the Bureau of Land Management have been busily creating HSI (Habitat Suitability Index), PATREC (Pattern Recognition), HC (Habitat Capability), IHICS (Integrated Habitat Inventory and Classification Systems), WFHR (Wildlife and Fish Habitat Relationships), and HEP (Habitat Evaluation Procedures) models almost without pause. Most are single-species models, others supposedly represent communities. Agency loyalty demands a certain amount of missionary defense of your own personal acronym, but there are few real differences in the underlying concepts or in the eventual output.

The primary differences among models lie in the assumptions required to produce each model and the problems created by those assumptions. Rather than discuss relatively minor differences among methods and models, I would like to briefly describe the basic concepts, some assumptions derived from those concepts, a few of the problems created by these assumptions, and some directions required to reach a solution.

Concepts

The underlying concepts in virtually all wildlife habitat models are straight out of Leopold's (1933) "Game Management." Schamberger and O'Neil (1986) suggested the defining concepts for HSI models are habitat (food and cover) and carrying capacity (usually expressed as a function of limiting factors). Starting with these concepts, it seems reasonable to propose that wildlife populations levels are determined by the quality of habitat and to conclude that appropriate measures of habitat quality will express potential carrying capacity. Such a conclusion, however, is a quantum jump requiring substantial oversimplification of complex systems at great cost in resolution. Habitat and carrying capacity, as concepts, are far easier to understand when they do not have to be expressed numerically.

Assumptions

Reducing concepts to numbers causes oversimplification because it is usually possible to include only a few factors of environment in a model. Selecting the appropriate factors requires some assumptions about the parameters of major importance and the ways those parameters influence animals. To indicate the difficulty in making a good assumption, I will examine two essentially generic models in a very superficial way: the elk coordination model and the grizzly bear cumulative effects model.

Most models of elk habitat in the Northern Rockies and the Pacific Northwest (for example, Leege 1984; Thomas and others 1979; Wisdom and others 1986) are basically similar. To a greater or lesser degree, all have been developed from the same habitat and carrying capacity assumptions:

1. Elk habitat quality is a function of cover and forage;
2. Carrying capacity of elk habitat is limited by roads.

It is important to recognize, in this and other wildlife models, that these larger assumptions very often mask specific, but hidden, assumptions produced by parameter definitions. In the elk model, thermal cover for elk is defined as a stand of conifers 40 feet tall with canopy closure over 70 percent, while hiding cover is defined as vegetation obstructing observation of 90 percent of an elk at 200 feet. Any stand not classified as cover is a foraging area (Thomas and others 1979).

Whether inadvertently, or by intent, these definitions effectively remove forage as a variable in the model. At the same time, they force acceptance of two invalid assumptions: (1) that a forest stand with less than 90 percent hiding cover throughout has no hiding cover value, and (2) that a forest stand with less than 70 percent crown canopy closure has marginal thermal cover value.

The carrying capacity assumption in the elk model is based on numerous replicated samples of data showing that elk avoid open roads. The fact that they cannot as effectively utilize habitat adjacent to roads (Lyon 1983) becomes the implicit, but partially hidden, assumption that loss of habitat effectiveness is harmful to the health of an elk population.

An identical masking of assumptions can be seen in the grizzly bear Cumulative Efffects Model (CEM) (Yellowstone Ecosystem). Although a much larger and more complex construction than any of the elk models, the CEM was also initiated with a habitat assumption and a carrying capacity assumption (Weaver and others 1986):

1. Area habitat quality is substantially a function of cover and food availability;
2. Disturbance determines the ability of a bear to use a specific habitat.

The definition for habitat in the CEM was developed from coefficients derived in analysis of a large data base describing scats, feeding sites, and seasonal food values (Mattson and others 1986). Within the model, edge density, seasonal equity, and protein concentrations provide additional subjective adjustments to calculated coefficients.

One hidden assumption, the emphasis on food values in the derivation of these coefficients, probably removes cover as a variable in the model. However, cover is restored as a part of the carrying capacity assumption where hiding cover is defined as vegetation hiding 90 percent of a bear at 200 feet; different disturbance coefficients are assigned in cover and noncover situations. Again, but only by implication, there are hidden assumptions that a stand with less than 90 percent hiding cover has no hiding cover value, and that losses of habitat effectiveness are damaging to the health of a bear population.

Problems

Critics of wildlife habitat modeling will see in the preceding discussion strong evidence of fatal flaws. No evidence, however, has so far indicated that either of these models is wrong. Both may, in fact, provide exactingly correct answers as long as the right questions are being asked. Schamberger and O'Neil (1986) emphasized that these are "...practical, operational planning models; designed to assess impacts of change; and based on a narrow definition of both habitat and carrying capacity." They should not be considered "...research models, carrying capacity models, population predictors,..."; or a host of other things they are not.

If there is a fatal flaw in wildlife habitat modeling, it will almost certainly be found in the restricted operational definitions of habitat and carrying capacity. However, the restricted definitions are not the real problem, they simply represent clear evidence that the kinds of information utilized to build habitat models are probably inadequate and may be of the wrong kind.

One of the flaws most often emphasized is the question whether data describing habitat selections by free-ranging animals indicate preferences instead of providing valid recognition of conditions required for survival. Why this should even be considered important is not clear to me. Like many biologists, I can see no positive value in identifying the absolute minimum of habitat conditions required to prevent local extinction.

However, the question is not totally ridiculous. It could produce a positive change in the research designs we use for identifying habitat parameters. Except for localized application, animal preference for a specific habitat condition is not the relevant question. If habitat models are to function with accuracy, they must be built on data derived from studies of specific daily stress, physiological or behavioral requirements, and responses of animals to identified stress conditions. If we knew what the habitat was providing for the animal, preference would not enter the picture. More important, alternative habitat structures that provide the same thing could be identified and extrapolation through modeling would become an important management tool.

A second flaw in habitat models is that carrying capacity assumptions always presume changes in the habitat will produce changes in wildlife populations. Disregarding the awesome power of Murphy's Law, there are several other ways for this assumption to prove invalid. Random variations in the weather can reverse almost any prediction. For most game animals, negative changes in habitat quality are likely to produce increased management restrictions to maintain the same wildlife population in a poorer habitat. And, finally, many of the wildlife species of greatest interest are extremely adaptable to environmental change.

The greatest potential for a fatal flaw in habitat modeling lies in the short, logical step to the assumption that models are real. This step, unfortunately, cannot be prevented if the models are to serve any useful purpose. Nevertheless, it supplies a further reason for making every effort to improve the quality of models to a level that will provide accurate, if not precise, numerical representations of the real world.

Solutions

There is little question that models of wildlife habitat can provide the means of evaluating existing and future wildlife habitats. Not every model will be successful, however, and in the degree it is possible to do so, wildlife habitat models must be "validated." I use this term in the sense defined by Shugart and West (1980): "...testing does not make models 'valid'; it simply gives one an idea about the reliability and, hence, the utility of a given model."

Unfortunately, a number of realities weigh heavily against any large-scale validation efforts. Wildlife habitat models can be created at a greater rate than they can be tested, and few scientists believe that sound research can be conducted at the experimental level required by most models. Validation, particularly over a large region, requires far better wildlife census techniques than are currently available for the majority of species.

Some investigators have suggested that it may be more logical to approach validation of wildlife habitat models through comprehensive testing of the underlying assumptions. To this end, I would further suggest that models should only be contructed on assumptions framed so that (1) no hidden assumptions are inadvertently created, and (2) each assumption is itself a testable hypothesis. It is not essential that every assumption be tested, but it is essential that assumptions be clearly stated and that they represent relationships with meaningful biological explanations.

ADEQUACY OF SUCCESSIONAL INFORMATION

According to Johnson (1979: 238), ecologists have been attempting to define the concepts of succession for nearly 130 years. The period before 1900 was "...formative, during which most of the architecture of the theory was layed out. This was followed by a developmental...period [1900-1930] dominated by Clements and Cowles, [and]...a radically different view...in the ideas of Gleason...." Johnson considers the period 1930 to 1947 a scholastic interval, presumably a period in which previous writings were studied and evaluated. After 1947, Johnson continues, "...there was a major loss of faith in the traditional ideas of succession." The result "...is the confused period in which we still find ourselves."

Johnson predicted the development of a new view of community dynamics profoundly different than succession, but the evidence from the short decade since his prediction is that we are still working our way through the "confused period." Descriptions of community dynamics have become more significant in the ecological literature of recent years. Whether they provide a profoundly different view of succession is open to interpretation. Most of our apparent progress seems to have been made in the development of larger and more sophisticated computer models rather than in major modifications of successional concepts.

Succession Models

There are, in fact, computerized succession models in mind-boggling profusion. Shugart and West (1980) reviewed more than three dozen forest dynamics models and classified 19 of them as forest succession models. A symposium on forest succession and stand development held in 1981 (Means 1982) contained 18 papers--more than half of which mentioned some kind of computer model. A quick review of the Wildlife 2000 Symposium (Verner and others 1986) shows attempts to link wildlife models with PROGNOSIS, DYNAST, FORPLAN, ECOSYM, HABSIM, TWIGS, FORHAB, SAMM, and several other models. The symposium this week will provide three to five additional models at either a conceptual or functional level.

However, while there is no shortage of models designed to predict succession, the wildlife manager might still ask what it is that is being predicted and whether the predictions have any basis in reality. Even more important, the manager might ask whether these models predict anything of value to wildlife. These are not questions that can be answered unequivocally, but the answers will not do much to increase your confidence.

Utility of Models

Accuracy and potential for extrapolation are extremely limited in most succession models. Just as wildlife habitat models are restricted by their assumptions, succession models are restricted by a lack of consistency in basic theory. One result, noted by Henderson (1982: 80), is that "The literature abounds with descriptive studies of succession. Yet when one wishes to investigate a particular area or sere, it becomes readily apparent that hard data are inadequate...." Franklin (1982: 167) proposed "...that successional theory developed solely from study of one ecosystem is almost invariably going to be a special case, inapplicable in detail, to another ecosystem." His solution was a general statement in which ecosystem change is described as a function of species life histories, environment, and stochastic variation. He noted that the formula is so general "...it could well bring despair to ecologists."

It is clearly a "no win" situation when existing data are too specific and a model of general application will produce widespread despair. And this is not the only problem. Succession models are almost always faulted for dealing with the wrong information in a way that is only indirectly applicable to the question at hand. Smith (1982) remarked: "It is an occupational disease of silviculturists to deal with the regeneration stages more than the final ones, of ecologists to deal mostly with the late stages, and of each group to fail to consider the whole process adequately."

Probably the major failing of existing models as related to applications in wildlife management is the tendency to treat trees as the only component of the forest community. Shugart and West (1980) classified their sample as tree models, gap models, or forest models on the basis of the way tree development was represented. In no case was the early seral development of understory vegetation considered. Other authors have noted a tendency for succession to focus on trees (Pfister 1982; Zamora 1982), sometimes even to the point of suggesting that succession starts at 4 inches d.b.h.

If wildlife management requires succession models with a little more sophistication than 4 inches d.b.h., wildlife managers will have to specify what is required. In general, this has not been done because the required specifications must come out of properly designed wildlife habitat models.

Solutions

Whatever their faults, forest succession models can usually be validated, or tested for reliability, because the vegetation being predicted will stand still for adequate census. Nevertheless, succession models, like wildlife models, can be created at a greater rate than they can be tested, and nonselective validation will certainly absorb more resources than are readily available for this purpose. Until we resolve the inability of succession models to handle some limited geographic extrapolation, along with the required array of areas, seres, species, and treatments, the proliferation of models is certain to exceed the potential for validation.

These realities have not, so far, resulted in the necessary restructuring of succession theory to accommodate known variation. And, as long as computer storage capabilities can be expanded, it may not be necessary to develop a better theory at all. Some investigators have already decided to take a pragmatic approach to succession modeling through comprehensive storage of vast data collections. At this point, I find it hard to disagree. It may be more intellectually stimulating to develop and modify a new succession theory, but current progress in solving practical land management problems is taking place in the computer.

DISCUSSION AND CONCLUSIONS

Succession and wildlife management, along with many other visible phases of wildland management, appear to have succumbed to a computer revolution. Whether that produces applause or gnashing of teeth should be of little concern if the people in charge of the computers do not abrogate their responsibility. Wildlife habitat models can examine and evaluate forest environments with greater precision and at far greater speed than ever before. Forest succession models can predict growth and structure of plant communities more accurately and with greater speed than ever before. Combinations of these models have a potential for predicting with virtual certainty landscape structure and wildlife carrying capacity into the foreseeable future. The ability to make such predictions is a driving variable in planning and an almost daily justification for management action. With so much riding on the outcome, we are surprisingly overconfident about the quality of these models.

It is my conclusion that we should be asking a few more and a lot harder questions. We have wildlife models that produce scalar values rather than numbers, that depend on concepts of sometimes questionable validity, that are limited by hidden or unstated assumptions, and that stray with some regularity from biologically meaningful assessment. We have succession models that lack a strong basic concept, that are too general to be useful or too specific to have meaning, and that either way provide the wrong kind of information.

It is entirely possible we will one day create a kind of Computer Nirvana in which input of real data to accurate models of wildlife habitat and forest succession will output precise estimates of habitat structure and animal numbers over any acceptable time period. Meanwhile, we probably should remember that predictions of changes in wildlife populations over time are only as good as the habitat models and the models predicting succession.

REFERENCES

Berry, Kristin H. 1986. Introduction: development, testing, and application of wildlife-habitat models. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife

2000. Modeling habitat relationships of terrestrial vertebrates: Report of a symposium; 1984 October 7-11; Stanford Sierra Camp, Fallen Leaf Lake, CA. Madison, WI: University of Wisconsin Press: 3-4.

Franklin, Jerry F. 1982. Forest succession research in the Pacific Northwest: an overview. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 164-170.

Henderson, Jan A. 1982. Succession on two habitat types in western Washington. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 80-86.

Johnson, E. A. 1979. Succession an unfinished revolution. Ecology. 60: 238-240.

Leege, Thomas A. 1984. Guidelines for evaluating and managing summer elk habitat in northern Idaho. Wildl. Bull. 11. Idaho Department of Fish and Game. 37 p.

Leopold, Aldo. 1933. Game management. New York: Charles Scribner's Sons. 481 p.

Lyon, L. Jack. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry. 81(9): 592-594, 613.

Mattson, David J.; Knight, Richard R.; Blanchard, Bonnie M. 1986. Derivation of habitat component values for the Yellowstone grizzly bear. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 222-229.

Means, Joseph E., ed. 1982. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory. 170 p.

Pfister, Robert D. 1982. Designing succession models to meet management needs. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 44-53.

Salwasser, Hal. 1986. Modeling habitat relationships of terrestrial vertebrates--the manager's viewpoint. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates: Report of a symposium; 1984 October 7-11; Stanford Sierra Camp, Fallen Leaf Lake, CA. Madison, WI: University of Wisconsin Press: 419-424.

Schamberger, Melvin L.; O'Neil, L. Jean. 1986. Concepts and constraints of habitat-model testing. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates: Report of a symposium; 1984 October 7-11; Stanford Sierra Camp, Fallen Leaf Lake, CA. Madison, WI: University of Wisconsin Press: 5-10.

Shugart, H. H.; West, D. C. 1980. Forest succession models. Bioscience. 30: 308-313.

Smith, David M. 1982. Patterns of development of forest stands. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 1-4.

Thomas, Jack Ward; Black, Hugh, Jr.; Scherzinger, Richard J.; Pedersen, Richard J. 1979. Deer and elk. In: Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture, Forest Service: 104-127.

Verner, Jared; Morrison, Michael L.; Ralph, C. John., eds. 1986. Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates: Report of a symposium; 1984 October 7-11; Stanford Sierra Camp, Fallen Leaf Lake, CA. Madison, WI: University of Wisconsin Press. 470 p.

Weaver, John; Escano, Ron; Mattson, David; Puchlerz, Tom; Despain, Don. 1986. A cumulative effects model for grizzly bear management in the Yellowstone ecosystem. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 234-246.

West, D. C.; Shugart, H. H., Jr.; Botkin, D. B. 1981. Forest succession: concepts and application. New York: Springer-Verlag. 517 p.

Wisdom, Michael J.; Bright, Larry R.; Carey, Christopher G.; Hines, William W.; Pedersen, Richard J.; Smithey, Douglas A.; Thomas, Jack Ward; Witmer, Gary W. 1986. A model to evaluate elk habitat in western Oregon. Publ. No. R6-F&WL-216-1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 36 p.

Zamora, Benjamin A. 1982. Understory development in forest succession: an example from the Inland Northwest. In: Means, Joseph E., ed. Forest succession and stand development research in the Northwest: Proceedings of the symposium; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 63-69.

USING VEGETATION CLASSIFICATIONS TO GUIDE FIRE MANAGEMENT

Stephen F. Arno and William C. Fischer

ABSTRACT: The advent of "fire management" has increased the need to understand and predict fire effects on vegetation. Such prediction is greatly complicated by the many factors that influence fire characteristics and plant response. Nevertheless, a few approaches have been developed to synthesize fire effects information by vegetation types. These include hypothesized models of postfire succession for groups of habitat types and more detailed classifications of successional communities and pathways within some individual habitat types. This predictive information is used to set realistic goals for use of prescribed fire in forest planning and to preplan fire suppression under different scenarios for diverse areas of forest land.

INTRODUCTION

For thousands of years fire has been the principal initiator of succession in northern Rocky Mountain forests (Habeck and Mutch 1973; Mehringer 1985; Mehringer and others 1977). Since the late 1800's, however, Euroamerican settlement and land-use practices have altered the occurrence and role of fire in this region. A primary mission of Federal forestry in the western United States at the beginning of the 20th century was to suppress fire, which was viewed almost entirely as a destructive and unnecessary agent (Pyne 1982).

By the mid 1900's, many ecologists and foresters had noted that undesirable successional changes, fuel accumulations, and threats to tree vigor accompanied a lack of fire in some of the forest and range types (LeBarron 1957; Pyne 1982; Weaver 1943). Evidence of the necessity of returning fire in some form to many of these ecosystems continued to mount. In the 1970's the U.S. Department of Agriculture, Forest Service, the U.S. Department of the Interior, National Park Service, and other agencies recognized this need by transforming the fire suppression policy into a much broader policy called "fire management." This new policy includes suppression of unwanted fires, but also attempts to return fire as a process to the wildlands (Fischer 1980; Kilgore 1983; Nelson 1979). In wilderness as well as in commercial forests, "prescribed fire" will be used. This is defined as fire burning under conditions that were planned ahead of time to accomplish desired effects (Fischer 1978; Martin and Dell 1978).

The advent of fire management has brought about a great need to understand and predict fire effects on vegetation. Meeting this need is complicated by the fact that fire is a variable treatment, ranging from light burning in the forest understory that causes minimal mortality to spectacular crown fires that can kill the tree layer over large areas during the course of a few hours. Furthermore, an individual fire often burns at different severities leaving a mosaic of treatments on the landscape.

The principal factors affecting the kind of fire treatment that occurs on a given site include weather conditions, fuel moisture, topography, and the successional stage of vegetation. This latter factor involves vegetation's role as fuel. Fire may spread primarily through dead vegetation such as litter and duff, downed woody material, and cured grasses and forbs. Additionally, living vegetation such as understory conifers can serve as a fuel ladder that allows torching into the overstory. If surface fuels are adequate, a dense tree layer can support a running crown fire.

Fuel loadings, fire behavior, and fire effects are strongly influenced by characteristics of the vegetation, including its productivity, decay rate, community structure, and flammability. These characteristics are directly related to the successional community type and indirectly linked to the site or potential vegetation type. Effects of fire are heavily influenced by fire-resistance and regeneration mechanisms of tree and undergrowth species.

MODELING FIRE EFFECTS

The effects of different fire treatments within a given habitat type have been predicted by modeling the effects of fire on the principal species of trees and undergrowth plants. This is done using a "selected attributes-multiple pathways model" based on life-history characteristics of each species (Connell and Slatyer 1977; Noble and Slatyer 1977). This conceptual approach for portraying postfire succession was initially applied to fire management planning in Glacier National Park and the Lewis and Clark National

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Stephen F. Arno is a research forester and William C. Fischer is a supervisory research forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Forest (Cattelino and others 1979; Kessell and Potter 1980). Current use of this approach in fire management is limited, perhaps because it requires detailed information on individual species and predictions are more qualitative than quantitative.

Since 1980, Fischer and several co-authors have expanded the application of selected attributes-multiple pathways models to characterize postfire succession in groups of "habitat types," site types based on potential vegetation (Crane and Fischer 1986; Fischer and Bradley 1987; Fischer and Clayton 1983; Kessell and Fischer 1981). The forest habitat types of Montana (Pfister and others 1977) were placed into 11 "fire groups" based on similar responses of the tree species to fire and the occurrence of similar postfire successions (Davis and others 1980). Habitat types usually dominated by lodgepole pine stands were, for example, combined into one fire group; this group is highly susceptible to bark beetle epidemics that result in dramatic increases in loadings of large downed woody fuels. For each fire group, the authors presented information on the relationship of major tree species to fire, forest fuels, historical fire frequencies and severities, fire's role in plant succession, and fire management considerations.

Simple models depict hypothesized successional pathways for each fire group (fig. 1 and 2). The

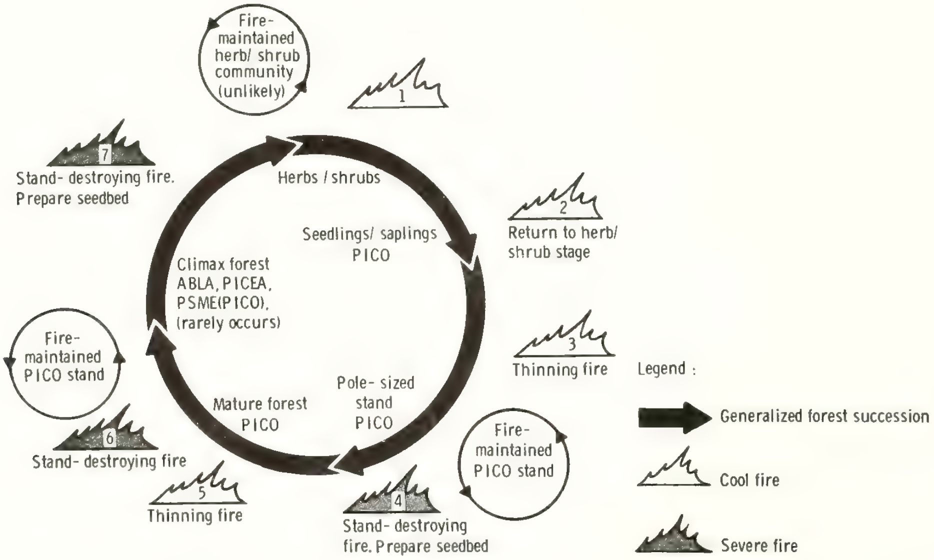
Fire-maintained herb/ shrub community (unlikely)
1
7
Stand- destroying fire. Prepare seedbed
Herbs / shrubs
2
Return to herb/ shrub stage
Seedlings/ saplings PICO
Climax forest ABLA, PICEA, PSME(PICO), (rarely occurs)
Fire-maintained PICO stand
3
Thinning fire
Legend :
Pole- sized stand PICO
Mature forest PICO
6
Stand- destroying fire
Fire-maintained PICO stand
Generalized forest succession
5
Thinning fire
4
Stand- destroying fire. Prepare seedbed
Cool fire
Severe fire

Figure 1--Generalized forest succession in Fire Group Seven: cool habitat types usually dominated by lodgepole pine (from Fischer and Bradley 1987).

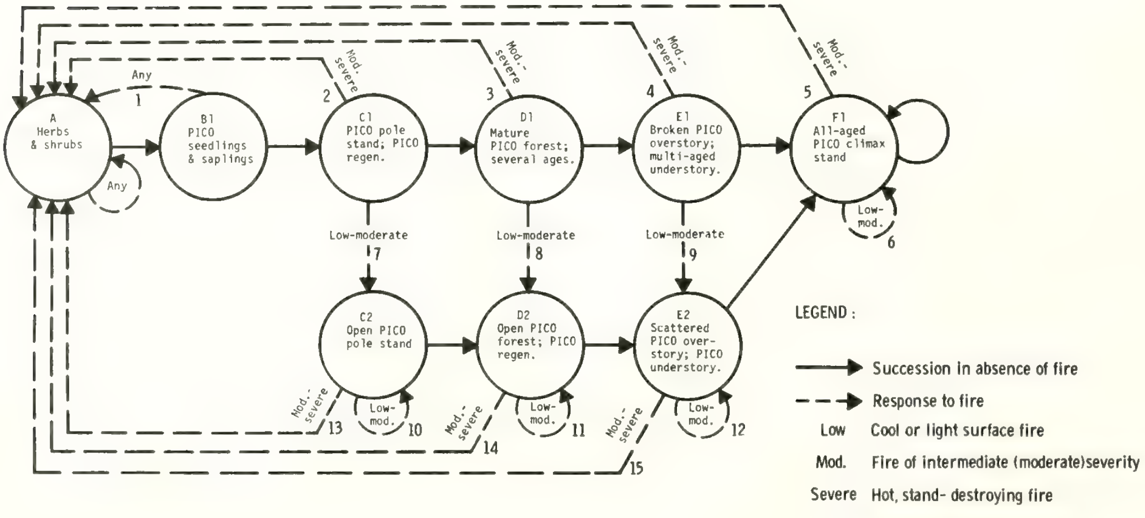
Any
1
A Herbs & shrubs
Any
B1 PICO seedlings & saplings
2
Mod.-severe
C1 PICO pole stand; PICO regen.
3
Mod.-severe
D1 Mature PICO forest; several ages.
4
Mod.-severe
E1 Broken PICO overstory; multi-aged understory.
5
Mod.-severe
F1 All-aged PICO climax stand
Low-mod.
6
Low-moderate
7
Low-moderate
8
Low-moderate
9
C2 Open PICO pole stand
D2 Open PICO forest; PICO regen.
E2 Scattered PICO over-story; PICO understory.
Mod.-severe
13
Low-mod.
10
Mod.-severe
14
Low-mod.
11
Mod.-severe
15
Low-mod.
12
LEGEND :
Succession in absence of fire
Response to fire
Low Cool or light surface fire
Mod. Fire of intermediate (moderate)severity
Severe Hot, stand- destroying fire
1, 2, etc. Reference number, (see text)

Figure 2--Hypothetical fire-related successional pathways for lodgepole pine habitat types in Fire Group Seven (from Fischer and Bradley 1987).

major structural stages are shown--for example, herbaceous community, a shrubfield, and various tree stages--and the differences in dominant tree species are indicated. The models also depict the common successional pathways that result from imposing fires of different severities on each structural stage (fig. 2).

FIRE GROUP USES

Habitat types serve as a principal element of land stratification for forest plans on the National Forests. Fire groups have been used as a means to integrate fire considerations in forest plans (Stiger 1980). They are also used as a basis for ranger district and National Forest fire management plans (Davis 1978, 1979b). For example, National Forest fire management plans include a decision process for determining the appropriate response to any unplanned ignition that might occur. This planned response to fire assesses the resource, property, and social values at risk on each site. The probable responses of these values to a given fire are predicted, including the likely spread of the fire into areas having other values at risk. This presuppression planning employs the fire ecology information presented by habitat type groups in designing cost-effective strategies for dealing with each fire. It may be classified as a wildfire and confined, contained, or suppressed; or it may be declared a prescribed fire and allowed to burn.

Appropriate uses of prescribed fire to accomplish certain resource management objectives are presented for each habitat type group. These fire-use considerations include recommended frequencies of burning, procedures for hazard reduction, forage production, site preparation, stocking control, and recreation site maintenance (Fischer and Bradley 1987). On some National Forest ranger districts, fire groups are also used to stratify information and data collected in evaluating the effects of prescribed fires.

Wilderness fire management planners have used fire groups in conjunction with land types to relate potential fire behavior and fire effects to specific areas of land (USDA Forest Service 1981, 1983). This has provided the documentation necessary to begin the process of returning fire to its role as a natural occurrence in wilderness. For example, fire groups provide a basis for assessing the natural role of fire in maintaining mosaics of successional communities within wilderness (Davis 1979a; Holdorf and others 1980; Royce and others 1979). Fire groups and cover types have been used as categories for summarizing data on surface fuel loadings and predicted fire behavior in northern Rocky Mountain forests (Brown and Bevins 1986; Brown and See 1981).

Fire groups have been published for the forest habitat types of Montana (Fischer and Bradley 1987; Fischer and Clayton 1983) and central Idaho (Crane and Fischer 1986). Fischer and co-authors are currently developing fire groups for the forest habitat types of National Forests in the Rocky Mountain Region--Colorado, Wyoming, and South Dakota (review draft manuscript completed) and for forest habitat types of Utah (review draft estimated for June 1988).

SUCCESSIONAL CLASSIFICATIONS

Successional classifications for individual habitat types have been developed for a few of the major types in western Montana and central Idaho. These classifications provide detailed insight for predicting the effects of wildfire and silvicultural applications of fire. The classifications are based on a large number of sample stands in each habitat type. Most of the "treated" stands were burned by stand-replacing wildfire, clearcut and broadcast burned, or dozer-piled and burned. Adjacent "untreated" stands on the same site were sampled when available, to represent a "control."

The classification approach developed in western Montana and being used in the Northern Region of the Forest Service could be considered a simple extension of habitat type classification (Arno and others 1985, 1986; Keane 1987, this proceedings). In this approach, a habitat type phase is subdivided into "structural stages" and into compositional "community types" based on synthesis of data from sample stands (see figs. 5 and 6 in Keane, this proceedings). Probable pathways of succession or stand development are shown as arrows linking community types in the classification diagram. To provide insight for vegetation management, the classification also lists the treatments and site or stand conditions associated with each posttreatment community type (Arno and others 1985). An interactive computer program developed as a companion to this model supplies quantitative predictions of vegetal response to treatments (Keane 1987).

An alternative approach to successional classification within individual habitat types is being applied in central Idaho--in the Forest Service Intermountain Region (Steele 1984, this proceedings; Steele and Geier-Hayes 1987a, 1987b). The objectives are similar to those of Arno and others (1986), but the classifications are constructed in a different manner. Each community is divided into three strata--the tree, shrub, and herb layers. For each layer a diagram depicts the relative position of indicator species on a successional time scale, from early seral to climax (fig. 3). These successional relationships are used to designate "layer types" which collectively constitute the community type. Linkages of layer types to wildfire and prescribed fire treatments are provided based on interpretation of sample stand data.

SYNTHESIZING DETAILED INFORMATION

Finer detail in using vegetation classifications to guide fire management is hampered because fire behavior and fire effects are strongly related to other aspects of vegetation in addition to the

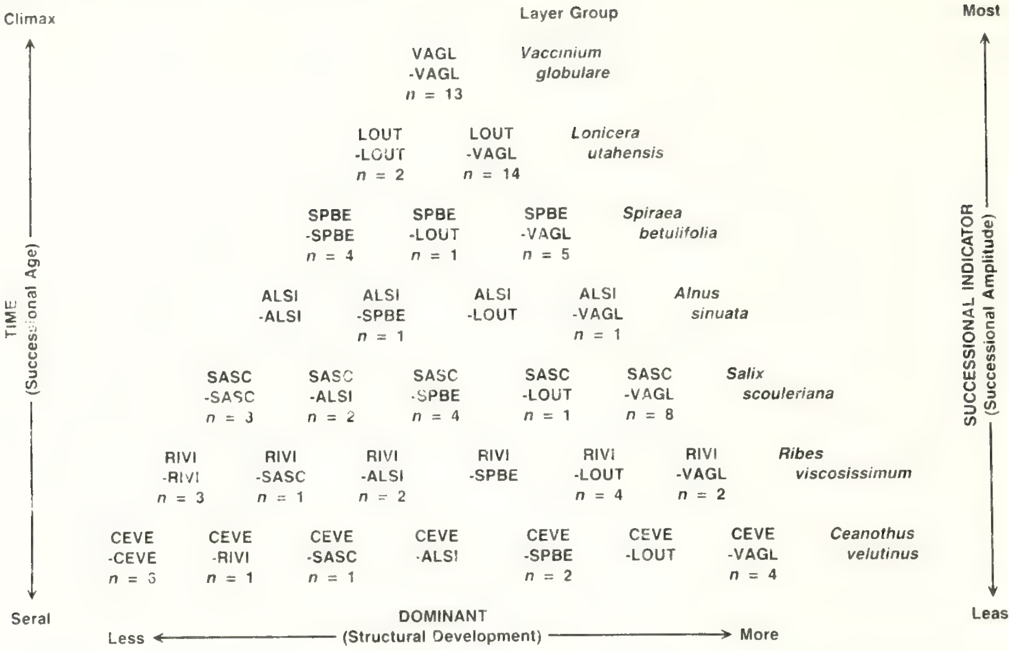

Figure 3--Classification model of shrub layer types in the *Abies grandis*/*Vaccinium globulare* habitat type (from Steele and Geier-Hayes 1987a).

successional community type. For instance, loadings of down woody fuels and juxtaposition of stand types contribute to how a fire burns. While characteristics of vegetation are of primary importance in managing timber, wildlife habitat, and range resources, fire managers have the additional concern of superimposing a highly variable treatment on the vegetation.

Reporting information on effects of certain kinds of fires on individual species in certain habitat types is often feasible, and may allow land managers to make more definitive predictions of fire effects. Both the Steele (1984) and Arno and others (1986) classifications presented predicted responses of individual tree and undergrowth species to fire based on sample stands. The work of Stickney (1980, 1985, 1986) and Geier-Hayes (1987), among others, also showed the response of individual species to particular fire treatments by habitat types. The Fire Effects Information System (Fischer, this proceedings) synthesizes all available fire response information by species and by plant community types. The advantage of this system is that detailed information will be made widely accessible to land management through the computer.

Land managers and specialists should, however, keep in mind that predicting response of complex vegetal communities is more difficult than evaluating responses of individual species. Moreover, fire, like natural vegetation, is itself a complex variable. Therefore it seems essential that vegetal information to guide fire management be obtained through a variety of classifications and syntheses of field observations and research information.

REFERENCES

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1986. Characterizing succession within a forest habitat type--an approach designed for resource managers. Res. Note INT-357. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Brown, J. K.; Bevins, C. D. 1986. Surface fuel loadings and predicted fire behavior for vegetation types in the northern Rocky Mountains. Res. Note INT-358. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Brown, J. K.; See, T. E. 1981. Downed dead woody fuel and biomass in the northern Rocky Mountains. Gen. Tech. Rep. INT-117. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Cattelino, P. J.; Noble, I. R.; Slatyer, R. O.; Kessell, S. R. 1979. Predicting the multiple pathways of plant succession. Environmental Management. 3(1): 41-50.

Connell, J. H.; Slatyer, R. O. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist. 111: 1119-1144.

Crane, M. F.; Fischer, W. C. 1986. Fire ecology of the forest habitat types of central Idaho. Gen. Tech. Rep. INT-218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 86 p.

Davis, K. M. 1978. Lolo National Forest revised fire management policy. Missoula, MT: U.S. Department of Agriculture, Forest Service, Lolo National Forest. 102 p.

Davis, K. M. 1979a. Cabinet Mountains Wilderness interim fire management plan. Libby, MT: U.S. Department of Agriculture, Forest Service, Kootenai National Forest. 30 p.

Davis, K. M. 1979b. Troy Ranger District fire management plan. Libby, MT: U.S. Department of Agriculture, Forest Service, Kootenai National Forest. 92 p.

Davis, K. M.; Clayton, B. D.; Fischer, W. C. 1980. Fire ecology of Lolo National Forest habitat types. Gen. Tech. Rep. INT-79. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 77 p.

Fischer, W. C. 1978. Planning and evaluating prescribed fires--a standard procedure. Gen. Tech. Rep. INT-43. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Fischer, W. C. 1980. Fire management techniques for the 1980s. The Ames Forester. 66: 23-28.

Fischer, W. C.; Bradley, A. F. 1987. Fire ecology of western Montana forest habitat types. Gen. Tech. Rep. INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 95 p.

Fischer, W. C.; Clayton, B. D. 1983. Fire ecology of Montana forest habitat types east of the Continental Divide. Gen. Tech. Rep. INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 83 p.

Geier-Hayes, K. 1987. Occurrence of conifer seedlings and their microenvironments on disturbed sites in central Idaho. Res. Pap. INT-383. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p.

Habeck, J. R.; Mutch, R. W. 1973. Fire-dependent forests in the Northern Rocky Mountains. Quaternary Research. 3: 408-424.

Holdorf, H.; Martinson, A.; On, D. 1980. Land system inventory of the Scapegoat and Danaher portion of the Bob Marshall Wilderness. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 71 p.

Keane, R.E., II. 1987. Forest succession in western Montana--a computer model designed for resource managers. Res. Note INT-376. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Kessell, S. R.; Fischer, W. C. 1981. Predicting postfire plant succession for fire management planning. Gen. Tech. Rep. INT-94. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Kessell, S. R.; Potter, M. W. 1980. A quantitative succession model of nine Montana forest communities. Environmental Management. 4: 227-240.

Kilgore, B. M. 1983. Fire management programs in National Parks and Wilderness. In: Lotan, J. E., ed. Proceedings of the Intermountain Fire Council and Rocky Mountain Fire Council "Symposium on Fire: Its field effects;" 1982 October 20-22; Jackson, WY. Missoula, MT: Intermountain Fire Council: 61-91.

LeBarron, R. K. 1957. Silvicultural possibilities of fire in northeastern Washington. Journal of Forestry. 55: 627-630.

Martin, R. E.; Dell, J. D. 1978. Planning for prescribed burning in the inland Northwest. Gen. Tech. Rep. PNW-76. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 67 p.

Mehringer, P. J., Jr. 1985. Late-Quaternary pollen records from the interior Pacific Northwest and northern Great Basin of the United States. In: Bryant, V. M., Jr.; Holloway, R. G., eds. Pollen records of late-Quaternary North American sediments. Dallas, TX: American Association of Stratigraphic Palynologists: 167-189.

Mehringer, P. J., Jr.; Arno, S. F.; Petersen, K. L. 1977. Postglacial history of Lost Trail Pass Bog, Bitterroot Mountains, Montana. Arctic and Alpine Research. 9(4): 345-368.

Nelson, T. C. 1979. Fire management policy in the National Forests--a new era. Journal of Forestry. 77(11): 723-725.

Noble, I. R.; Slatyer, R. O. 1977. Postfire succession of plants in Mediterranean ecosystems. In: Mooney, Harold A.; Conrad, C. Eugene, tech. coords. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. Gen. Tech. Rep. WO-3. Washington, DC: U.S. Department of Agriculture, Forest Service: 27-36.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Pyne, S. J. 1982. Fire in America--a cultural history of wildland and rural fire. Princeton, NJ: Princeton University Press. 654 p.

Royce, A.; Wetzsteon, H.; Fifield, N.; DeZell, M.; Hinman, J.; Bethke, F.; Abbot, D.; Stiger, E. 1979. Anaconda-Pintlar Wilderness fire management plan. Missoula, MT. U.S. Department of Agriculture, Forest Service, Northern Region. 114 p.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58(1): 29-39.

Steele, R.; Geier-Hayes, K. 1987a. The grand fir/blue huckleberry habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Steele, R.; Geier-Hayes, K. 1987b. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 132 p. Review draft.

Stickney, P. F. 1980. Data base for post-fire succession, first 6 to 9 years, in Montana larch-fir forests. Gen. Tech. Rep. INT-62. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

Stickney, P. F. 1985. Data base for early postfire succession on the Sundance Burn, northern Idaho. Gen. Tech. Rep. INT-189. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 121 p.

Stickney, P. F. 1986. First decade plant succession following the Sundance Forest Fire, northern Idaho. Gen. Tech. Rep. INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service Intermountain Research Station. 26 p.

Stiger, E. M. 1980. The fire situation, Lewis and Clark National Forest, phase I. Discussion draft, level I, fire management analysis. Great Falls, MT. U.S. Department of Agriculture, Forest Service, Lewis and Clark National Forest. 28 p.

U.S. Department of Agriculture. 1981. Fire management action plan: Scapegoat wilderness and Danaher portion of the Bob Marshall Wilderness. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

U.S. Department of Agriculture. 1983. Fire management plan: Bob Marshall Wilderness and Great Bear Wilderness. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry. 41: 7-14.

Herbert D. Holdorf

ABSTRACT: Vegetative mapping projects can be designed using principles inherent to the design of soil surveys. The first step is to work with map users to identify specific objectives for the survey. Map users identify the uses for which soil is to be evaluated, the level of detail required, and the properties or attributes of soil important to map objectives. Mappers advise users about technical feasibility and cost of map objectives. Map objectives strongly influence selection of map base, map scale, kind of map units used, and mapping techniques. Soil taxonomy is used to name and describe the composition of map units. Habitat types, or similar classification systems, can be used in vegetative mapping the same way. The principal advantage of doing so is to facilitate the description of vegetative complexity within map units.

INTRODUCTION

The soil survey staff has much experience in designing mapping projects. Design of vegetative mapping projects can benefit from this experience. The purpose of this paper is to describe the steps in designing a soil survey and how they might apply to vegetative mapping projects.

SETTING PROJECT OBJECTIVES

Before a mapping project can be designed, objectives for the map must be defined. Both map users and mappers must be involved in setting objectives. The following is a partial listing of items which should be considered in setting map project objectives:

1. The uses for which the vegetation or potential vegetation is to be evaluated. Wildlife habitat, timber productivity, response to silvicultural treatment, range forage productivity, and response to livestock grazing are examples of objectives for which vegetation is commonly evaluated.

2. The level of generalization required. Is the objective to evaluate timber productivity and silvicultural response on stands of a minimum of 5 acres in size or to evaluate suitability and limitations to timber management in a large undeveloped watershed? A good way to describe map detail is the minimum size delineation to be used.

3. The properties or attributes of vegetation that are important to map objectives. Wildlife habitat analysis will likely be based on a different set of vegetative properties than objectives for evaluating timber productivity and response to silvicultural treatment. It is important that specific interpretations and the properties from which they are derived are identified. For example, a map of elk habitat might require interpretation of hiding and thermal cover, winter forage value, summer forage value, and calving habitat. The biologist should specifically identify which vegetative properties determine suitability for each element of habitat.

There are some difficulties in working with users to set map objectives. The most common is the tendency of users to combine too many objectives in a single map project. They will reason that as long as you're in the field, you might as well gather all the data they might need. Maps may have multiple objectives provided they require the same level of map detail and are based on the same, or closely related, sets of properties. Incompatible objectives greatly increase the number of delineations on the map, which in turn obscures information important for any given objective and greatly increases project costs.

Map users will sometimes identify objectives requiring different levels of detail. For example, they may desire a map which allows the evaluation of large areas for timber management and response by individual stands to silvicultural treatment. A good strategy to use in this situation is to map the entire area at the broadest level of detail required. This map, in turn, is used to identify which areas should be mapped in greater detail for the second objective. Such an approach produces legible maps which are less expensive than those obtained by detailed mapping of an area without prior knowledge of its general features.

In summary, mappers need to specifically understand user's objectives before designing map projects. Project success will be judged by the user based upon how well their expectations are met. In turn, users need to understand how objectives affect map quality and cost. It is

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erbert D. Holdorf, Regional Soil Scientist, orthern Region, USDA Forest Service, Missoula, T.

preferable that the user understand which objectives are technically or economically impractical in the project planning stage rather than have their expectations for the project not met. Once project objectives are established, the mapper may begin designing the project.

MAP BASE AND MAP SCALE

One of the first decisions in the design of a mapping project involves the selection of a suitable map base and scale. Map bases are usually photographs which display vegetative and land use patterns or topographic maps which display slope and relief. Either type of map base may be appropriate to a project depending upon the types of properties to be mapped and their relationships to properties visible on the base. The map base selected should be the one which provides the user with the best understanding of such relationships.

Selection of map scale is determined by the minimum size delineation required to meet project objectives. This minimum size delineation is commonly about 1/4-inch square (about 5 acres at 1:24,000 scale or 40 acres at 1:63,360 scale). Users who need information about small areas are not distracted by numerous boundaries and symbols, hence, a minimum scale map base is appropriate. Users who evaluate large areas are distracted by cluttered maps; consequently, the map base scale selected is usually larger than that required for minimum size delineations.

NAMING AND DESCRIBING MAP UNITS

Every map needs a legend in which map units are named. Map units on soil maps are named for kinds of soil. Map units on vegetative maps will be named for habitat types or classes in some equivalent classification system. It is important for mappers to recognize that the classes in classification systems are conceptual. They provide a common standard for naming, interpreting and communicating. Map units named for these classes contain real soils or plant communities. Map units named for a single kind of soil or plant community will almost always contain soils or plant communities with properties outside the range of the named soil or plant community. They are mapping inclusions. Inclusions cannot be excluded from delineations by practical field mapping methods because of natural variability. When map units are designed and named, judgment must be exercised about the effect of inclusions on map objectives. In soil surveys, inclusions that have properties that cause them to behave like the named soil for map objectives are treated as similar. If inclusions have properties that cause them to behave differently than the named soil, they are treated as dissimilar. Dissimilar soils are of minor extent and do not affect map objectives. Similar inclusions can be extensive, but are not dominant. These principles can be used when naming and designing vegetative map units.

Following are two examples of how vegetative map units might be named and their composition described using formats from soil surveys.

Map Unit A: Subalpine Fir/Beargrass

This map unit is on southerly aspects at 4500 to 6000 feet elevation. Subalpine fir/beargrass is the major habitat type. Douglas-fir/blue huckleberry, beargrass phase is included at lower elevations and is similar. These habitat types occupy about 85 percent of the unit.

Included are up to 15 percent dissimilar habitat types. Subalpine fir/bluejoint is in moist draws and the forest understory has higher productivity for elk forage. Subalpine fir/menziesia is on included northerly aspects and has higher value for elk security cover.

Map Unit B: Ponderosa Pine/Idaho Fescue-Douglas-Fir/Ninebark Complex

This map unit is on dissected mountain slopes at 3000 to 4500 feet elevation.

Ponderosa pine/Idaho fescue is the major habitat type on southerly aspects. Douglas-fir/Idaho fescue is similar on upper slopes. These habitat types occupy about 50 percent of the unit.

Douglas-fir/ninebark is the major habitat type on northerly aspects. Douglas-fir/snowberry is similar on lower slopes. These habitat types occupy about 40 percent of the unit.

Included are up to 10 percent dissimilar community types. Small meadows dominated by Idaho fescue and bluebunch wheatgrass are on narrow ridges and have higher forage productivity than the major habitat types.

MAPPING TECHNIQUES

The level of detail required by map objectives affects selection of field mapping techniques. Objectives requiring detail and high purity of map units will require mappers to sample each delineation to verify its composition and boundary. This is very expensive; consequently, map projects will be for small areas such as research plots or areas scheduled for intensive vegetative treatment.

Objectives requiring less detail and purity permit mapping techniques that rely on sampling of representative delineations and extrapolation of ground truthed data to unsampled delineations via aerial photo or remote sensing interpretation. These mapping techniques require enough ground truth sampling to establish reliable relationships between sets of properties important to map objectives and an aerial photo or remote sensing "signature". Intensive ground truthing may be required for general map objectives when adequate signatures cannot be found. Mappers and map users should reassess map objectives if this situation happens frequently. It is important to note that reliability should be set by map objectives and not by the mapping technique employed. If map users have requested unrealistic levels of reliability given time and funds, they should be notified, and a decision made as to the appropriate sampling technique to employ.

PROJECT EXECUTION

The following is a partial listing of quality control practices used in soil surveys which should be considered in vegetative mapping.

1. Map units should be tested against objectives during mapping. Each map unit should have a unique set of interpretative values and properties which relate to project objectives. Unneccesary map units clutter the map and obscure needed information.

2. Every map project should have a report. A map and legend cannot convey all needed information to the user. There are always properties or variabilities that cannot be described without narrative description.

3. A legible map is the first requirement for success. Cartographic qualities such as line weight, symbol placement, and delineation density should receive attention.

SUMMARY

Vegetative mapping projects should be carefully planned to insure project success. Users should be consulted to set objectives and establish relationships between objectives and properties of vegetation. Mappers should advise users concerning the technical feasibility and costs of achieving objectives. Selection of map base, map scale, types of map units used, and mapping techniques are all strongly influenced by objectives. A narrative report that describes composition of map units and properties important to project objectives is recommended.

CONCEPTS AND TECHNIQUES OF VEGETATION MAPPING

David W. Roberts and Stephen V. Cooper

ABSTRACT: Mapping vegetation involves plotting the distribution of vegetation classes on base maps. This paper distinguishes between mapping potential vegetation (habitat types) and current vegetation (community types) and addresses the characteristics unique to each problem. Guidelines are presented for effective sampling of vegetation, predictive models for vegetation mapping are compared, and methods for validation of the predictive models and the completed maps are presented.

INTRODUCTION

Vegetation comprises the largest biotic component of natural ecosystems, and directly or indirectly determines the distribution and abundance of many other natural resources. One of the common objectives of vegetation classification is to create classes that can then be mapped to portray the distribution of the vegetation characteristics on the landscape. Such maps provide valuable information for many land management practices. The objective of this paper is to present some guidelines for mapping vegetation using existing classifications, and to introduce or review some useful techniqes. We provide only cursory guidelines on the actual field procedures of vegetation mapping. Instead, we focus on procedures for extrapolating ground-truth mapping data to large unmapped areas, and on methods of map validation.

IDENTIFYING FACTORS CONTROLLING VEGETATION DISTRIBUTION

Throughout this paper, we distinguish between two different but related objectives of vegetation mapping. One common objective is to map potential natural (climax) vegetation (habitat types in the sense of Daubenmire and Daubenmire 1968) from existing vegetation patterns. Strictly speaking, this should be considered site mapping (of physical or abiotic factors), rather than vegetation mapping, but it is commonly considered an aspect of vegetation mapping. Alternatively, the objective may be to map existing vegetation according to a successional community classification (for example: Arno and others 1984; Steele and Geier-Hayes 1987) or by dominance types. The primary reason for distinguishing between potential vegetation and existing vegetation (however classified) is that the distribution of the two is determined by different sets of factors, and it is these factors that form the basis of predictive models of vegetation distribution.

Aside from artifacts in the migration of flora over time, the distribution of potential natural vegetation is determined strictly by factors of the physical environment. The radiation, moisture, and nutrient budgets are the primary determinants. Although the radiation budget of sites is relatively difficult to measure effectively, potential direct radiation can be computed from latitude, aspect, and slope (Swift 1976). The effect of shading from adjacent landforms is difficult to estimate, but algorithms (see Austin and others 1984) and templates exist for calculating the portion of the sun's trajectory blocked by adjacent landforms for specified days of the year. In practice, except for extremely dissected terrain, the effect of shading can be ignored; if necessary an ancillary variable can be introduced to simulate shading. If estimates of diffuse radiation are then added to estimated direct radiation, it is possible to estimate the daily radiation received by a site, and then to integrate over seasons or a year. When radiation is not computed directly, a utilitarian radiation index can be calculated as:

$$\text{index} = (-\cos(\text{azimuth}-30) + 1\ ) / 2.$$

Index values range from 0.0 on NNE slopes to 1.0 on SSW slopes.

Moisture budgets are also difficult to measure, but can be estimated from topographic and soils data. The relative moisture budget of a site is determined primarily by elevation, topographic position, and soil characteristics. In areas with sufficient weather stations it is possible to estimate the increase in precipitation that occurs with an increase in elevation using a linear regression model. If available precipitation data are insufficient, it is reasonable to assume that relative precipitation is linearly proportional to elevation, at least for sites not on the elevational extremes. Caution should be exercised in extrapolating elevation-precipitation regressions beyond the immediate area for which they are derived; in the northern Rocky Mountains where the spines of many mountain ranges are oriented north-

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David W. Roberts is Assistant Professor, Department of Forest Resources and Ecology Center, Utah State University, Logan, UT; Stephen V. Cooper is an ecologist and private consultant, Missoula, MT.

south, windward west slopes are more moist than east slopes at the same elevation.

Topographic position, soil texture, and soil depth determine the proportion of precipitation that is available to vegetation on a site by controlling run-on and run-off, as well as soil moisture storage and availability (Hewlett 1982; Pritchett and Fisher 1987). Distance from open water and adjacent stream order also serve as useful indices to site moisture availability (Martin 1970). In some mountainous and foothill terrain, prevailing winds strongly modify the moisture-temperature regime and vegetation pattern. Prevailing winds affect site moisture balance through increases in precipitation or evaporation. These effects can be modeled by creating a categorical variable for the specific range of aspect directly opposed to the prevailing winds.

Finally, those aspects of the nutrient budget that determine potential vegetation distribution are determined in part by the chemistry of the soil parent material and soil cation exchange capacity (Pritchett and Fisher 1987). It is not necessary to know the relative nutrient values of the different parent materials, but rather simply to allow for their contributions to the predictive model. Often, classifying diverse parent materials into a few classes such as calcareous sedimentary, noncalcareous sedimentary, mafic igneous, felsic igneous, and metamorphic is sufficient. As we will explain, fragmenting environmental variables into numerous class variables may cause difficulty in developing a predictive model.

Employing this method of predicting potential natural vegetation, radiation is calculated from latitude, aspect, and slope; moisture is indexed by elevation, geographic and topographic position, soil texture and soil depth; and nutrient status from parent material. All these data can be derived from topographic, soils, land type, or geological stratigraphy maps. Because it is the current vegetation, rather than the potential vegetation, that is evident in aerial photography or remote sensing imagery, these sources of information must be used with caution. The same successional community can occur in several potential vegetation types and may obscure differences in potential vegetation.

In contrast, the distribution of successional community types is determined largely by disturbance type (including management practices), prior community composition, and chance. Following a disturbance, chance may play a large role in determining the resulting vegetation, as for example differences in cone crops for tree species in adjacent stands causing one of several possible tree species to become dominant. This stochastic effect greatly increases the difficulty in predicting successional communities for areas recently disturbed. Little or none of the information necessary for prediction may be available on maps, especially if maps of disturbance events (such as fire boundaries) are not available. However, the physical environment limits the set of possible successional communities at any given site, and it is helpful to have or simultaneously develop a potential vegetation map to aid in predicting successional community types on the landscape. Additionally, because the objective is to map what is currently present, aerial photography and remote sensing imagery are extremely useful.

OBTAINING GROUND-TRUTH MAPPING DATA

Assuming typical time and resource constraints, any large mapping effort will require the extrapolation of limited ground-truth data to a much larger area. Whether mapping potential vegetation or current vegetation, effective stratification is essential; the stratification must reflect the factors that control the distribution of the vegetation.

For potential vegetation, the controlling factors are parent material, soil texture and depth, elevation, aspect, slope, and topographic position. The simplest procedure is first to delineate the area into parent material classes. Soil texture and depth are likely to be highly correlated within the parent material classes, but substantial variation may still exist. If soils maps are available, depth and texture classes should be delineated within the parent material classes. This two-step stratification leads to fairly homogeneous regions. A roughly comparable level of stratification can be obtained from land type maps being compiled for each National Forest by the Forest Service, U.S. Department of Agriculture.

Elevation, aspect, and slope are continuous variables, and it is not necessary or advisable to formally delineate elevation or aspect classes within the parent material--soil strata previously identified. Choose areas for mapping that exhibit sufficient topographic relief to expect potential vegetation differences, but which are not characterized by fine-scale or microtopography. These areas should consist of several hundred acres so that many topographic positions are represented, and should be chosen to represent, in the aggregate, all elevation and aspect combinations within the region. While collecting the ground-truth data, the mapper should keep a running list of elevation and aspect combinations mapped, so that common areas will not be oversampled and less common combinations missed. It is important to map areas large enough that several potential vegetation types are included, so that the local pattern of adjacent types is determined. In addition to helping in validation of the map, some extrapolation techniques can make use of adjacent vegetation types in a predictive model.

For mapping successional vegetation (community types), a different stratification is employed. If the potential vegetation has been previously or simultaneously mapped, this should serve as the first level of stratification. Aerial photography can then be used to delineate apparently homogeneous areas. Finally, if maps of the distribution of previous fires, or if fire history data are available, this information can also be entered into the stratification.

The scheme for sampling existing vegetation within strata is more problematic than for potential vegetation because the classes bear no necessary relation to position on the landscape, and it is difficult to determine the set of successional community types that exists in a region. The approach we have employed is to map relatively large sample areas and determine which successional community types occur within each potential vegetation type. Frequently, depending on the disturbance regime for the area, relatively few of the potential community types actually occur on the landscape. These communities are then correlated with stand age (if known), aerial photography color or texture, and remote sensing spectral signatures (if available). If remote sensing data are to be used, the sample stands must be sufficiently large and homogeneous to ensure that reliable spectral data can be obtained for these stands without blending or noise from adjacent types.

EXTRAPOLATION OF GROUND-TRUTH DATA

Ground-truth data can be extrapolated based on either a special-purpose model developed by the mapper, or by a statistical model using a computer. Statistical models have advantages in sophistication and objectivity, but vegetation distribution does not fit easily into the assumptions underlying many statistical models, and a carefully prepared special-purpose model may provide greater accuracy. The primary advantage of statistical models is the great speed with which they can process the data and predict class membership for new areas to be mapped.

The first step in developing a special-purpose model is to classify variables as categorical variables, which have classes but no necessary order (for example, parent material), or scalar variables, which are ordered from low to high (for example, elevation). Categorical variables are suitable for development of dichotomous keys; scalar variables can be used in quantitative indices. Examine the categorical variables first, searching for variables that partition the vegetation types fairly cleanly. For example, igneous parent materials may support one set of potential vegetation types; sedimentary parent materials support another. Even if the two sets overlap, distinguishing the parent material narrows the possible choices. Using the variable that achieves the best split first, repeat the process for each of the two branches in the tree until there are no clean splits left. Then, for each branch of the tree, develop a predictive model from the scalar variables by plotting the distribution of vegetation classes using the scalar variables as axes. Vegetation classes of mid-slope positions are effectively plotted by locating sample plots by elevation and aspect on polar coordinate graph paper. While the special-purpose model admittedly is subjective, it is essential to allow as little ambiguity as possible, as ambiguous choices lead to frustration when attempting to use the model for numerous stands.

If statistical models are preferred, there are at least two choices--linear discriminant analysis (LDA) and classification trees (CT). LDA is similar to linear regression, but the objective is the prediction of class membership for new objects in existing classes (Afifi and Clark 1984). CT is a computer algorithm that employs a procedure similar to that outlined above for the special purpose model (Breiman and others 1984).

LDA weights and combines data from samples of known classes to form a linear function that best reproduces the original classification (Verbyla 1986). This linear function is known as the "discriminant function" or "classification function" (Afifi and Clark 1984). Values of the classification variables for each stand of vegetation are entered into the linear function to predict to which of several classes it should be assigned. Depending on the computer program employed, the item may simply be assigned to the class with the highest probability, or the probability of membership in each class may be reported. LDA can employ some scalar variables directly, but categorical variables must be entered as dummy variables (1 or 0) for each possible class.

LDA has several limitations for predicting vegetation distribution. If there are numerous parent material and soil textures, the number of dummy variables gets very large; if the number of possible predictor variables is large relative to the sample size, serious bias in prediction may result (Verbyla 1986). Second, vegetation distribution may be highly nonlinear with respect to environmental variables; LDA will nevertheless attempt to fit a linear relation. For example, if slope aspect is not transformed to reflect radiation or temperature gradients, LDA will attempt to use the aspect values as a linear scale from 0 to 360. Third, LDA is susceptible to outliers (unusual points) and noise (sampling error or random variation) (Verbyla 1987). Additionally, assumptions regarding the variance/covariance structure of the data employed in LDA are commonly violated by vegetation-site data. However, LDA is still commonly used as it provides an objective method for prediction, is well understood, and is widely available on computers.

Steele (1986) used logistic discriminant analysis, a more robust discriminant technique, for terrain-vegetation modeling. In a comparison to LDA, the logistic discriminant analysis was notably more accurate; an additional 15 percent of the plots were correctly classififed. We are currently investigating the value of logistic discrimination in vegetation mapping.

CT is a partitioning technique that forms dichotomous keys from sample data (Breiman and others 1984). Each variable is examined in turn to determine the optimal split point (for scalar variables) or optimal partition (for categorical variables) to produce the most homogeneous classes. The variable with the best split is employed first, and the procedure is then repeated for each branch of the tree to produce an optimal dichotomous key. CT assumes that the relation between vegetation and scalar environmental variables is monotonic, rather than linear, and is much more flexible than LDA in choosing and combining variables. CT is much less susceptible to outliers and noise than is LDA (Verbyla 1987). As a final product, CT provides a dichotomous key, rather than the probability distributions and linear functions provided by LDA, to predict the membership of new samples.

Unfortunately, CT is computationally intensive. For each scalar variable, for N unique values, there are N-1 possible split points, each of which will be examined. For categorical variables, the number of possible splits is potentially much greater, according to the formula:

$$\sum_{X=1}^{(N-1)/2} \frac{N!}{X!(N-X)!} \qquad \sum_{X=1}^{N/2} \frac{N!}{X!(N-X)!}$$

if N is odd　　　　if N is even

For five possible values, the number of splits is only 15; for 10 possible values the number becomes 637 possible splits. The run-time for the program is approximately proportional to the number of splits, so that categorical variables with large numbers of possible values should be avoided. As a final disadvantage, CT can be expensive to run and is not widely available.

MAP VALIDATION

Regardless of the method used to map new areas, the models employed or the maps so constructed must be validated. The apparent accuracy of predictive models is assessed by comparing the predicted values to the sample values. The apparent accuracy is subject to bias, however, as the same data are used to develop and test the model. The bias can be estimated and reduced by cross-validation (Verbyla 1986). In cross-validation, the data are divided into a number of groups. The data in one group are held out, and the model is developed on the remaining groups. The values of the samples held out from the model are then predicted and compared to the actual values. This procedure is repeated until all groups have been held out once in turn, and the model has been developed n times for n groups. The fraction of correct predictions is the cross-validated accuracy, and the difference between the apparent accuracy and cross-validated accuracy is an estimate of the model bias. Cross-validation methods vary in the relative amount of data used for development and testing, and are reviewed by Verbyla (1986).

Alternatively, the models can be tested with the bootstrap resampling method (Efron 1983; Verbyla 1986). Bootstrapping involves withdrawing a number of samples at random with replacement, and developing the model on the remaining samples. The values of the withdrawn samples are predicted and compared to the actual values. This process is repeated a large number of times, and the mean number of correct predictions is the bootstrap estimate of model accuracy. Bootstrapping provides better estimates of accuracy than does cross-validation, but requires considerably more computer time to calculate.

Ideally, the predictive model should be developed for data collected one year, and employed to map sufficient area for testing the following year. The test set should be chosen as a stratified random sample of stands. If random points are chosen, rather than random stands, the points should be discarded if they are in areas of nonhomogeneous topography or near apparent ecotones. When the test stands are compared to the predicted values, it is possible to identify which portions of the predictive model failed, at least for the special purpose and CT models. In these cases it is possible to redirect the sample design to collect more data in problem areas and to reduce sampling where the model predicts sufficiently well.

APPLICATIONS

Both LDA and CT were employed in an effort to map potential vegetation in Bryce Canyon National Park, based on a classification by Youngblood and Mauk (1985). Bryce Canyon National Park, an area of approximately 50 square miles in southern Utah, is on the eastern edge of the Paunsaugunt Plateau at elevations from approximately 6,800 feet to 9,100 feet. The forested portion is mixed conifer forest, principally in areas of climax ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and white fir (*Abies concolor*).

A total of 125 sample plots of forest vegetation were stratified in the field by elevation, aspect, topographic position, and parent material. Sample plots were keyed to the *P. ponderosa* (PIPO), *P. menziesii* (PSME), or *A. concolor* (ABCO) series (climax tree species). The blue spruce (*Picea pungens*) series is present in the Park, but is too rare to predict reliably.

Ground-truth mapping indicated that the distribution of series was determined primarily by the radiation and moisture budgets. For all sample plots, mid-July radiation (concurrent with estimated onset of moisture stress) was calculated from latitude, aspect, and slope (Swift 1976), and precipitation was estimated simply from elevation. The sample plots were then divided randomly into 10 groups for analysis and 10-fold cross-validation for both LDA and CT.

For the LDA, sample plots were assigned to the series with the highest value for the discriminant function (see example, table 1). The apparent accuracy of the model (using all data) was 80 percent, with a 10-fold cross-validated accuracy of approximately 70 percent (table 2). The cross-validated estimates show fair performance for the PIPO series, poor performance for the PSME series, and good performance for the ABCO series. The same 10 groups were analyzed by CT using elevation, radiation, and slope as classification variables. The apparent accuracy was 83 percent, with a 10-fold cross-validation estimate of accuracy of approximately 64 percent (table 3). Again, the model exhibits fair performance for the PIPO series, poor performance for the PSME series, and good performance for the ABCO series. The classification tree for the full data set is shown in figure 1.

Table 1--Linear discriminant model for predicting series. Determine appropriate series by calculating maximum probability function

Probability = elevation * c1 + solar radiation * c2 + constant

Series	c1 elevation (feet)	c2 solar radiation (langleys)	constant
PIPO[1]	0.080	0.125	-369.0
PSME[2]	0.085	0.103	-393.0
ABCO[3]	0.090	0.096	-429.0

[1] PIPO = *P. ponderosa* series
[2] PSME = *P. menziesii* series
[3] ABCO = *A. concolor* series

Table 2a--Apparent accuracy of LDA for full data set. Number of plots (with percent of actual in parentheses) is given for each combination of predicted and actual series

	Predicted		
Actual	PIPO	PSME	ABCO
PIPO	23 (77%)	6 (20%)	1 (3%)
PSME	6 (19%)	16 (52%)	9 (29%)
ABCO	4 (6%)	3 (5%)	57 (89%)

mean = 80 percent correct

Table 2b--Cross-validated accuracy of LDA for full data set. Number of plots (with percent of actual in parentheses) is given for each combination of predicted and actual series

	Predicted		
Actual	PIPO	PSME	ABCO
PIPO	19 (63%)	10 (33%)	1 (3%)
PSME	8 (26%)	11 (35%)	12 (39%)
ABCO	4 (6%)	3 (5%)	57 (89%)

mean = 70 percent correct

Table 3a--Apparent accuracy of CT for full data set. Number of plots (with percent of actual in parentheses) is given for each combination of predicted and actual series

	Predicted		
Actual	PIPO	PSME	ABCO
PIPO	27 (90%)	3 (10%)	0 (0%)
PSME	6 (19%)	20 (65%)	5 (16%)
ABCO	5 (8%)	2 (3%)	57 (89%)

mean = 83 percent correct

Table 3b--Cross-validated accuracy of CT for full data set. Number of plots (with percent of actual in parentheses) is given for each combination of predicted and actual series

	Predicted		
Actual	PIPO	PSME	ABCO
PIPO	23 (77%)	7 (23%)	0 (0%)
PSME	18 (58%)	4 (13%)	9 (29%)
ABCO	6 (9%)	5 (8%)	53 (83%)

mean = 64 percent correct

```
1) elevation <= 8420 feet
   2) slope <= 17.5 percent
      3) elevation <= 8090 feet ..... PIPO (22/32)
      3) elevation >  8090 feet
         4) elevation <= 8330 feet .. PSME ( 6/ 8)
         4) elevation >  8330 feet .. PIPO ( 3/ 4)
   2) slope >  17.5 percent
      5) elevation <= 7230 feet ..... PIPO ( 2/ 2)
      5) elevation >  7230 feet ..... PSME (10/13)
1) elevation >  8420 feet
   6) slope <= 4 percent
      7) elevation <= 8620 feet ..... PSME ( 4/ 4)
      7) elevation >  8620 feet ..... ABCO ( 3/ 3)
   6) slope > 4 per cent ............ ABCO (54/59)
```

Figure 1--Classification tree for predicting series for sample plots. For each terminal step of the key, the number of correct identifications and the total number of plots terminating at that step are given in parentheses.

The performance of both approaches reinforces our intuitive model of the distribution of series. The distribution of climax P. menziesii appears to cover a narrow range of environments in Bryce Canyon, and the differentiation between the PSME series and the other series is extremely subtle. Both of the objective approaches employed here performed poorly in distinguishing this series, with relatively greater success for the other series. For both approaches, the mistake is to assign PSME series plots to other series, rather than to assign other series plots to the PSME series.

The results demonstrate the need to perform cross-validation (or some other form of error checking) on the predictive models. The apparent accuracy for both models was significantly higher than the cross-validated accuracy, with prediction biases of 10 percent for LDA and 19 percent for CT. For predictive models developed on larger data sets, the expected prediction bias should be smaller, but the apparent accuracy will always be higher than the actual accuracy of the model.

In this example, LDA performed better than CT, but previous experience in comparative tests suggests that results vary among data sets. CT is possibly more sensitive to small data sets, and we are currently investigating the relative performance of these techniques on much larger data sets.

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REFERENCES

Afifi, A. A.; Clark, V. 1984. Computer-aided multivariate analysis. Belmont, CA: Lifetime Learning Publications. 458 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Austin, M. P.; Cunningham, R. B.; Fleming, P. M. 1984. New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. Vegetatio. 55: 11-27.

Breiman, L.; Friedman, J. H.; Olshen, R. A.; Stone, C. J. 1984. Classification and regression trees. Belmont, CA: Wadsworth Inc.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agricultural Experiment Station. 104 p.

Efron, B. 1983. Estimating the error rate of a prediction rule. Improvement on cross-validation. Journal of the American Statistical Association. 78: 316-331.

Hewlett, J. D. 1982. Principles of forest hydrology. Athens, GA: University of Georgia Press. 183 p.

Martin, F. C., Jr. 1979. A test of photogrammetric terrain mapping for ecological land classification in the Lolo Creek drainage, Montana. Missoula, MT: University of Montana, 130 p. Thesis.

Pritchett, W. L.; Fisher, R. F. 1987. Properties and management of forest soils. New York: John Wiley and Sons. 494 p.

Steele, B. M. 1986. Improved discriminant functions for terrain modeling. Unpublished paper on file at U.S. Department of Agriculture, Forest Service, Northern Region Office, Missoula, MT.

Steele, R.; Geier-Hayes, K. 1987. The grand fir/ blue huckleberry habitat type in central Idaho: Succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

Swift, L. W., Jr. 1976. Algorithm for solar radiation on mountain slopes. Water Resources Research. 12: 108-112.

Verbyla, D. 1986. Potential prediction bias in regression and discriminant analysis. Canadian Journal of Forest Research. 16: 1255-1257.

Verbyla, D. 1987. Classification trees: A new discrimination tool. Canadian Journal of Forest Research. 17: 1150-1152.

Youngblood, A. P.; Mauk, R. L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

VEGETATION MAPPING IN THE NORTHERN ROCKY MOUNTAINS

Barry L. Dutton

ABSTRACT: Vegetation mapping in many guises has been conducted throughout the northern Rocky Mountains. Cover types, habitat types, range sites, grizzly bear components, timber stands and vegetation types are examples of the mapping unit components used. Goal, costs, and success have varied. Most vegetation mapping data are not published and are not in a form for easy general access. New technologies including Geographic Information Systems should allow easier, more widespread use of vegetation mapping data and better communication among mappers. Vegetation mapping projects have many components and each must be planned for to ensure success.

INTRODUCTION

This paper reviews past vegetation mapping efforts in the northern Rocky Mountains and summarizes some important characteristics including mapping unit components, scales, acreages, and costs. Guidelines for conducting vegetation mapping projects are summarized with emphasis on proper planning and complete reporting of results.

NEEDS FOR VEGETATION MAPPING

Vegetation maps are used for a variety of purposes by many disciplines. This presents a dilemma to map makers who must decide whether to make a vegetation map with one purpose in mind or to try to satisfy the needs of several user groups. It is important for the mapper to know as much as possible about each discipline with potential use for the map. This can be achieved by extensive interdisciplinary training (the superman syndrome), or by involving specialists from different user groups in all phases of project planning and review.

PAST VEGETATION MAPPING EFFORTS

I will first review some examples of past vegetation mapping projects. This review is not comprehensive but illustrates the range of goals, intensities, and other characteristics of existing maps.

Several published vegetation maps are available that cover large areas of the northern Rocky Mountains. These include maps of potential vegetation such as Kuchler's map of the United States (1966) and Ross and Hunter's map of Montana (1976). Other large-area maps address individual species distribution such as Arno's map of *Larix lyalli* distribution (1970) or Morris and Kelsey's map of *Artemesia spp.* distributions (1973).

Most mapping projects, however, cover smaller areas and are designed for specific purposes. Table 1 illustrates some examples of recent vegetation mapping projects and their characteristics. Costs are for map preparation and do not include planning, materials, data compilation, report writing, and other tasks. These data suggest that many vegetation mapping efforts have similar costs for fieldwork. This is due to the fact that field methods are similar and involve a combination of map or photo interpretation and transects across the landscape for direct observations. The major differences in mapping projects are therefore in the expertise of individual field crew members and in the specifics of what data are recorded.

Habitat Type Mapping

Mapping habitat types has been popular among most state and federal agencies as well as large private forest land owners. Habitat type maps at various scales are available for many national forest and state forest lands in Montana. As greater interest has developed in using habitat type maps, further map refinement has occurred. The cost of mapping habitat types ranges from a few cents per acre for small-scale projects covering large areas to between 25 and 50 cents an acre for more detailed efforts at scales near 1:24,000.

Most mapping projects treat the taxonomic unit of habitat type as a mapping unit and do not have map unit descriptions explaining the actual distribution of types within map delineations. These maps are used for a wide range of planning and project purposes. They have proven useful both as a communications tool and as a source of substantial management information related to habitat types. The concept of habitat types is firmly planted in resource agencies and research institutions and will continue to be widely used.

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Barry Dutton is a natural resource consultant, Dutton Resource Consulting, Missoula, MT.

Table 1--Examples of vegetation mapping projects and costs for map preparation

Project Area	Map Units	Method	Scale	Acres	Costs ($/Acre)
Seeley Ranger District	Habitat types	Ground truth	1:24,000	55,000	0.27
Seeley Ranger District	Habitat types	Photo-interp	1:24,000	80,000	0.02
Lolo National Forest[1]	Habitat types	Ground truth and photo-interp	1:31:680	700,000	0.01
Crow Indian Reservation[1]	Range sites	Ground truth	1:24,000	1,200,000	0.16
BLM Dillon Resource Area	Range sites	Ground truth	1:63,360	748,000	0.33
Greenough Coop Grazing Association[2]	Range sites	Ground truth	1:24,000	70,000	0.28
Lewis and Clark National Forest	Timber stands	Photo-interp	1:24,000	134,169	0.02
Glacier National Park and Flathead National Forest	Vegetation types	Ground truth	1:24,000	33,500	0.60

[1] Ringleb, Rick. 1987. [Personal communication]. November 3. Huson, MT: Resource Analysis.

[2] Kennett, Greg. 1987. [Personal communication]. November 5. Missoula, MT: Missoula County Soil Conservation District.

Range Site Mapping

Range site mapping has been most popular with the Soil Conservation Service and the Bureau of Land Management. Range sites are a combination of soil, climate, and vegetation factors. This method has been developed for both grasslands and "grazable woodlands." Fieldwork mapping costs range from 15 to 50 cents per acre depending on scale, goals, and other factors. These mapping projects have also usually treated the taxonomic unit of range type as a mapping unit and lack map unit descriptions explaining the actual distribution of types within map delineations. These maps have also proven their long-term usefulness, again due to research linking plant composition and production to the types. It is likely that range site mapping will continue to be used in rangeland communities.

Timber Stand Maps

Timber stand or timber type maps are a form of vegetation map that is often overlooked. With improvements in recent years, these maps offer an excellent resource in areas with no other vegetation information. Skilled plant ecologists can expand these maps into vegetation type and habitat type maps with additional work. Most agencies and private companies with forest land holdings have classified their lands according to a timber type mapping system. Some maps use Society of American Foresters cover classes but recent classification schemes are much more sophisticated and informative. Most of the forest lands in the Forest Service Northern Region have type mapping. This work has mainly been accomplished by air photo interpretation and with limited ground-truthing. Costs have usually been less than 10 cents per acre. These maps will continue to be refined and updated for timber management purposes.

Grizzly Habitat Component Mapping

Grizzly bear component maps have been prepared for much of the grizzly habitat and some potential habitat in the northern Rockies (Leach 1986). Habitat components are delineated, which represent general vegetation conditions perceived as being important to bears. Examples of components include "avalanche chutes", "wet meadows", "mixed shrub fields," and others. This mapping method fell short of its goals and expectations. Problems included the lack of relationships to existing vegetation classifications and insufficient or erroneous documentation of community types and individual species. Costs for fieldwork were approximately 30 cents per acre (Weaver 1987). After careful evaluation of component mapping goals and results, Forest Service Northern Region wildlife personnel have worked with the regional ecology staff to implement a more detailed method of collecting vegetation information for habitat evaluation. Greater emphasis is being placed on delineating current and potential vegetation according to established classifications and methods. This method lets mappers use existing data on habitat types and other vegetation classifications. It also allows production of maps that are useful to various diciplines.

Vegetation Type Mapping

In 1986 the Forest Service Northern Region Ecology Program began producing maps of vegetation distributions based on the "vegetation type," a combination of current and potential vegetation characteristics. One goal of this method is to produce a map with utility for many user groups. Costs for fieldwork should be competitive with other methods and yield superior results. Data from the 1986 field season will be used to attempt correlations between vegetation and spectral classes in Glacier National Park and on the Flathead National Forest. Ecology Program personnel are compiling a manual on vegetation mapping to provide direction for mappers and to standardize methods for future projects.

ther Vegetation Maps

umerous smaller mapping projects have been onducted locally. Habitat type maps and maps of urrent vegetation have been compiled for esearch areas, experimental forests, timber ales, and other locations. Current vegetation aps have been made for small nature areas, ildlife refuges, and private properties. While hese projects cover relatively small areas, they epresent some important botanical locations and ill be the source of useful information for the uture.

EGETATION MAPS FOR THE FUTURE

ith this wealth of experience in vegetation apping, it seems we should be ready to design he ideal mapping system. However, there is onsiderable discussion about many basic issues n map project structure. Some believe that one ap can be generated to fulfill most needs of the arious user groups. This approach would allow ne field crew to produce a map instead of everal groups mapping the same area ndependently.

New technologies such as Geographic Information Systems (GIS) will have a major impact on vegetation mapping. Their greatest impact may be the enhancement of communication among various map user and producer groups. A GIS provides a centralized database to which all parties contribute. This effort may focus on creating a single vegetation map of the area, which is constantly refined as each group makes further investigations. If the "single map" approach is not adopted, a GIS will allow projects to be stored separately and integrated as needed. No matter what approach is taken toward vegetation mapping, a GIS will enhance communication between map users and producer groups, leading to maps that are more complete and more accessible.

Mapping projects are very complex undertakings. Despite a history of vegetation mapping experience in the northern Rocky Mountains, most projects lack important components which add significantly to their overall usefulness and accessibility. Vegetation mapping projects are often undertaken by individuals with expertise in some particular aspect of vegetation and it is these aspects upon which the map focuses. However, it is important to have an awareness of all components of a mapping project, how they fit together, and how each task leads to a finished product. Failure to plan for each component may diminish the usefulness of the final product.

The quality of a mapping project is directly related to the knowledge and experience of the participants. A team of several experienced vegetation mappers can accomplish much more than an army of untrained enthusiasts. In the northern Rocky Mountains, vegetation distribution and structure is very complex. Relationships to climate, landforms, soils, and other features present a nightmare to those making stratifications. It is absolutely essential that mapping project planners obtain the quality of expertise needed for all phases of project implementation.

MAPPING PROJECT COMPONENTS

Throughout a mapping project, participants should be aware of how each task fits into the project as a whole. Figure 1 illustrates a flow chart for mapping projects.

Plan -->-- Budget -->-- Order photos and other

materials -->-- Hire/contract -->-- Train -->--

Premap -->-- Fieldwork -->-- Review -->-- Enter

data -->-- Analyze data -->-- Digitize data -->--

Test map accuracy -->-- Write report -->--

Publish -->-- Distribute

Figure 1--Mapping project flow chart.

Planning Mapping Projects

The initial planning stage is extremely important since decisions about map scale, map unit type, and other concerns will affect all subsequent activities. The national cooperative soil survey program has addressed similar questions of map unit design, map scale, map bases, logistics, and other considerations. A half-century of soil mapping experience in the U.S. is an excellent source of information for planning vegetation mapping projects. It is significant that two speakers in the mapping section of this symposium are soil scientists. Table 2 illustrates a checklist for planning mapping projects.

Table 2--Mapping project checklist

Define the area to be mapped.

Assess available resources including funds, personnel, and specialized equipment.

Choose a map base.

Choose a map scale.

Determine priority user(s)--in some cases a project may be organized and designed for a specific purpose or user group; this is usually the group paying for the project.

Establish a tentative completion date for priority user(s).

Design a map unit description format which includes the information needed by the priority user(s) and the agency as a whole.

Identify a vegetation stratification that will meet project needs. Set standards for delineating strata or polygons and for describing map units.

Determine personnel requirements to match skills and time frame for the mapping project.

Investigate special considerations such as access, wilderness classification, road closures, harvest activities, unusual weather, or other factors which affect project efficiency.

Establish a procedure for evaluating the quality of the mapping project which is agreeable with all parties.

Choose a format for the final product including compilation, correlation, editing, and printing.

Review plans with all potential users and cooperating agencies as well as various resource specialists (have project managers budget time for a continuing involvement in planning, administering, and reviewing the project).

Draft a schedule for ordering photos and map base materials.

Budget and Manpower Requirements

Budget and manpower requirements vary according to the goals, extent, scale, and other characteristics of each project. Table 3 illustrates some generalized manpower requirements for various components of a vegetation mapping project. Where budgets are limiting, various strategies can be devised to provide the needed vegetation mapping information. One method is to first generate a small-scale map for the entire area using air photo interpretation, spectral analysis, or other remote sensing tools. This map can be used for general planning purposes. The area can then be prioritized according to needs for more detailed information. Ten-year timber management plans, wildlife concerns, and special projects may be used to prioritize the order of detailed mapping.

Important Mapping Considerations

Mapping projects involve many considerations and I have tried to concentrate on some of the most important. This is by no means a comprehensive review, but will give the reader an introduction to the kinds of subjects which must be addressed for a successful project. It is essential that mapping project participants have good communication on the key project elements. Basic terms such as mapping unit, taxonomic unit, polygon, strata, vegetation type, cover type, and others must be clearly understood by all personnel. These terms are often used in confusing and contradictory fashion in both conversation and reports. The basic concepts of plant ecology and mapping must be understood by all mapping personnel.

Table 3--Sample mapping project manpower requirements for a 100,000-acre vegetation mapping project (these figures are very general estimates)

Task	Person-days
Planning	15 - 30
Premapping	25 - 35
Fieldwork	100 - 200
Data entry and compilation	20 - 30
Digitizing	30 - 45
Report	30 - 45
Administration	30 - 45
Contracting	10 - 30
TOTAL PROJECT	250 - 450

One of the most commonly misunderstood distinctions is between map units and taxonomic units. Whenever you delineate a polygon in a landscape you almost always have more than one thing (one Taxonomic Unit) contained within. Many projects continue to label mapping units and individual polygons as single taxonomic classes without mentioning the other vegetation components. Table 4 illustrates the relationship between map units and taxonomic units.

High-quality map unit descriptions increase the usefulness of the maps and the confidence of map users. Map unit design is an important part of project planning and provides a logical framework for maintaining organization in complex landscapes. Figure 2 illustrates a sample map unit description.

Table 4--Taxonomic components of a vegetation mapping unit common on the Seeley Ranger District, Montana

Percent	Taxonomic class	Landscape position
80	ABLA/VACA	Nearly level terrace surfaces
15	ABLA/XETE-VAGL	Short, steep, south slopes in the northern portion of the unit
5	ABLA/GATR	Around seeps and on the floodplains of small streams

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ap Unit Name: ABLA/VACA - PICO Cover Type

xample Location of Typical Unit: The flat errace landscape surrounding the intersection of he North Fork road and Elk Creek in the NE 1/4 f the NW 1/4 of Section 23, T 18N, R 15W.

eology and Soils
andform(s): Glacial outwash terraces
arent material: Sandy, gravelly, cobbly, glacial utwash
andtype: 27-7
oil: Sandy-skeletal and loamy-skeletal, mixed, ndic Cryochrepts

opography
levation range: 5500-7000 feet
spects: All
lopes: 2-10% for the major vegetation type

abitat Types	% of Unit	Site Features
BLA/VACA	90	Occurs mostly on the nearly level surface of outwash terraces.
BLA/CLUN, VACA	5	Occurs mostly in small depressions and kettles within the outwash terrace surface.
LA/XETE, VAGL	5	Occurs on steep (25-50%) terrace edges or escarpments.

Strata or Cover Types for the Existing Vegetation

Cover Type	HT(s)	% of Unit	Site Features
PICO	ABLA/VACA & ABLA/CLUN, VACA	95	Level surfaces & depressions of outwash terraces.
PICO-PSME	ABLA/XETE, VAGL	5	Terrace edges and escarpments.

Special Considerations: There are significant amounts of PSME/VACA in this unit where it is mapped south of Deer Creek.

Species Composition of Major Strata or Vegetation Type(s)

Strata/Veg Type	Species	Constancy	Coverage(%)
A	PINCON	10	90
	ABILAS	10	2
	VACCAE	10	20
	VACGLO	2	5
	JUNCOM	2	7

Interpretations

Timber Management:
Wildlife:
Recreation:
Fire:

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gure 2--Sample mapping unit description.

Map units are designed in relation to project size, scale, goals, landscape complexity, and other considerations. Mapping unit types may include those dominated by one taxonomic unit (single-taxa units or consociations), and those with extensive coverage of two or more taxonomic units (complexes).

Size and type of polygons are, to a large extent, determined by the map scale. For instance, at a map scale of 1:24,000 it is not practical to delineate areas smaller than about 5 acres. Table 5 illustrates some relationships between map scale, polygon size, and mapping unit type (adapted from USDA-SCS Soil Survey methods). These different levels of intensity in mapping are refered to as mapping "orders" by soil scientists. Project planners should select an order of mapping to fit their project goals.

Data Extrapolation

Mappers must also be aware of the many kinds of extrapolation that are a part of mapping projects. Final map quality is directly related to the quality of extrapolations. It is essential that the persons responsible for extrapolations have the needed perspective and experience. Lack of qualified personnel to make these contributions is a common cause of quality problems. Forms of extrapolation in mapping projects include:

1. Extrapolating the characteristics of the portion of the polygon or vegetation type you view in traversing to that you do not observe.

2. Extrapolating the characteristics of polygons you visit to ones you observe from a distance with binoculars or other instrument.

3. Photo interpretation of polygon features when the polygon is only viewed on aerial photos and topographic maps.

4. Spectral class sampling and analysis for extrapolating vegetation types and mapping units.

Developing extrapolation or predictive skills is one of the most important parts of a mapper´s training. The mapping process should become one of confirming predictions, not discovering mysteries. To extrapolate knowledge gained from transects and traverses, the mapper must identify relationships between vegetation and terrain features such as elevation, aspect, soil, and geologic material. The combination of these relationships becomes a mental terrain model which the mapper is continuously testing and revising. This model acts as a personal mapping tool, as a structured means of communication between mappers, and as a source of hypotheses for statistical testing and other purposes. It is essential to recognize and document mental terrain models throughout the fieldwork and report stages.

Table 5--Relationships between mapping scale, polygon size, and mapping unit type. These figures are presented as a general guide and are subject to change due to local needs

Map scale	Polygon acreage Range (Average)	Type of mapping units
1:12,000 (or less)	1 - 20 (5)	Single-taxa units of vegetation types or phases of habitat types
1:24,000	5 - 100 (40)	Single-taxa units and some complexes of vegetation types, habitat types and phases of habitat types
1:24,000 to 1:100,000	20 - 500 (80)	Complexes of vegetation types and habitat types or habitat type groups
1:100,000 to 1:1,000,000	100 - 1000 (500)	Broad cover classes dominant species, lifeform groups or habitat type series

Map Accuracy Evaluation Procedures

Few efforts have been made in the northern Rocky Mountains to test the accuracy of vegetation maps. With the introduction of new technologies such as spectral analysis and new procedures such as the Forest Service Northern Region Ecodata System, accuracy checks are becoming more important to evaluate these innovations. While all projects should contain information about accuracy, it is especially important for pilot efforts.

Three accuracy types should be evaluted in mapping projects. Cartographic accuracy concerns the basic form of the map and the information placed on it (are polygons labeled correctly, do lines connect, etc.). Classification accuracy concerns the ability to predict a taxonomic class without direct, on-the-ground observation. Description accuracy includes how well the map unit and vegetation type descriptions represent true conditions at individual sites. By outlining accuracy goals and how each accuracy type will be tested, project planners can match these goals against manpower and funding requirements. Field personnel will have a better understanding of their tasks if these goals are clearly identified. These goals provide a framework for identifying areas during fieldwork which need further investigation.

Mapping Project Reports

Mapping projects in the Northern Rockies have often lacked a written report to accompany the maps and in many cases have lacked mapping unit or taxonomic unit descriptions. Throughout a mapping project, a tremendous amount of knowledge is acquired by field personnel conducting on-the-ground mapping. Vegetation mapping projects represent large financial investments and every effort should be made to capture as much information as possible for future use. Map completion alone should never be considered the final product. A written report should always accompany the maps to convey a wide variety of information to the map user. Table 6 illustrates some possible components of a vegetation project report. The effectiveness and usefulness of the final product is directly related to the knowledge and experience of field crew members and to the quality of presentation in the report.

Table 6--Sample components of a mapping project report

Statement of project goals
Identification of participants
Summary of procedures
Instructions on use of the information
Photos and/or maps
The map legend
Map unit descriptions
Discussions of vegetation distribution by current and climax type and by important individual species
Discussions of relationships between vegetation and topography, soils, climate, and other factors
Identification of areas with special mapping and description problems
Discussions of important species concerns such as endangered plants, poisonous plants, weeds, and wildlife foods
Results of modeling and other data treatment
Discussions of correlation procedures and elationship of the project to others
valuations of accuracy
stimates of project costs
eeds for further work

VEGETATION MAPS: PERSONALITIES AND DYNAMICS

For the first time in print, I want to address a few important aspects of mapping projects. The first of these is the high regard which each of us holds for our own mapping. This may relate to the fact that mapping is part "art," and an artist is always touchy about people criticizing or changing his or her work. This is also related to the fact that a mapper is faced with making order out of chaos or "discrete types" out of "continuums" and there are many subjective choise to be made in this process. Not everyone makes these choices the same way, which can lead to differences in the apperance of the final map. Such differences must be recognized and evaluated in correlation procedures and by accuracy testing. Interpretive differences are not serious except when they drift too far from the concepts defined by mapping units and project goals.

For whatever the reason, egos and tempers are easily aroused during reviews and accuracy checks of maps in the field. Mappers and map reviewers simply need to recognize this fact and attempt to maintain a cooperative attitude and a healthy sense of humor. One way of achieving peace of mind in mapping projects is to stop viewing maps as permanent, inflexible resources. With GIS and other technologies, we will soon be able to update maps and add new refinements with relative ease. A new view of maps as dynamic tools should reduce some of the conflicts which upset some projects.

SUMMARY

In the past few decades, large areas of vegetation in the northern Rocky Mountains have been mapped using a variety of systems with varied success. Costs for fieldwork have ranged from a few cents per acre for small-scale maps covering large acreages to between 25 and 75 cents per acre for more detailed efforts. Few of these projects include written reports and many lack any description of mapping units. New technologies such as GIS will likely improve future efforts by improving communication among mappers and providing a centralized repository for all map data. Vegetation mapping projects require careful planning and administration to ensure success. Map unit design, extrapolation methods, accuracy testing, and reports are examples of mapping project components that should not be ignored. The quality of the final product is directly related to the knowledge and experience of field crews and administrators.

REFERENCES

Arno, S. 1970. Ecology of Alpine Larch (Larix lyalli Parl.) in the Pacific Northwest. Missoula, MT: University of Montana. 264 p. Dissertation.

Kennett, Greg. 1987. Personal communication. November 5. Missoula, MT. Missoula County Conservation District.

Kuchler, A. W. 1966. Potential natural vegetation of the United States. New York: Ronald Press. 472 p.

Leach, Rose. 1986. Grizzly bear component mapping in the Northern Region. In: Contreras, Glen P.; Evans, Keith E., compilers. 1986. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 32-35.

Morris, M.; Kelsey, R. 1972. Distribution of sagebrush (Artemesia spp.) in Montana. Missoula, MT: School of Forestry. 36 p.

Pfister, Robert. 1987. [Personal communication]. November 10. Huson, MT: University of Montana, Lubrecht Experimental Forest.

Ringleb, Rick. 1987. [Personal communication]. November 3. Huson, MT: Resource Analysis.

Ross, R.; Hunter, H. 1976. Climax vegetation of Montana based on soils and climate. Bozeman, MT: USDA Soil Conservation Service. 64 p.

Weaver, John. 1987. [Personal communication]. Nov. 8. USDA Forest Service Northern Region, Missoula, MT.

USE OF GIS TO MAP VEGETATION IN EASTERN WASHINGTON

Glen O. Klock

ABSTRACT: Geographic Information Systems help make the job of vegetation mapping easier and more consistent. Examples are used to illustrate the use of such systems.

INTRODUCTION

Methods of mapping forest and range vegetation have changed with the advent of new technology. The earliest form of vegetation mapping involved drawing the extent of a vegetative type on maps in the field. In the late 1940's and 1950's, vegetative mappers began to use aerial photographs. Continued improvement in the transfer technology from the aerial photograph to the hard copy map has led to the many fine vegetation maps used by foresters today.

Whether mapping was by the field forester or the aerial photo interpreter, the boundary between vegetative types has to be drawn by the mapper. As these drawn boundaries are based on human judgment, the quality of the map is a direct function of the mapper's experience and skills. Thus qualitative differences occur among mappers, which often lead to map inconsistencies when more than one mapper is used on a forest or range vegetation-mapping project.

MULTI-SPECTRAL ANALYSIS

More recently, multi-spectral analysis has been successfully used as a tool to map forest and range vegetation. Whether the spectral image comes from an aircraft scanner, a satellite scanner, or the scan of a photograph, its interpretation depends upon correlating a spectral value with a given vegetative class. For example, a stand of Douglas-fir poles will have a different set of image spectral values than a ponderosa pine pole stand. Therefore, by setting the spectral band or limits for each vegetative class, computer analysis will draw a consistent boundary between our example classes of Douglas-fir and ponderosa pine.

This technique depends upon numeric values established with the computer to draw the boundary between vegetative types. Therefore, the boundaries between vegetative types are generally more consistent throughout the map project area by this method than by the traditional method employing human judgment to draw these boundaries. Knowledge of the spectral value limits used in establishing the boundaries are extremely useful for future remapping or monitoring of vegetative conditions.

This case example of using image spectral values to identify vegetative types would work fine if each species type and stand structure type within each species had a unique image spectral value. Often stands do not have unique spectral values, or the difference in spectral values between two classes is so small it is difficult to differentiate statistically. Therefore, additional aids often need to be used with multi-spectral imagery for vegetative mapping.

Each timber stand or range cover is well known to exist because of a set of environmental parameters, primary energy, moisture, and temperature. These environmental parameters are often a function of the site position such as elevation and slope aspect, particularly in eastern Washington and northern Idaho. Within a given map project area, these environmental parameters can be correlated with vegetative types. Often a successful ecological model can be designed which predicts the potential distribution of vegetative types within a homogeneous biogeoclimatic zone.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems (GIS) provide the opportunity to build, analyze, and display computer spatial data bases. Many "layers" of spatial data can be constructed, all georeferenced to the same map coordinates. These layers may consist of elevation, slope, aspect, soil type, annual precipitation, and so on, which all may relate to the presence or absence of a given vegetative type on a site. Again, using an example in the analysis of a multispectral image, it may be determined that there is no statistical spectral difference between stands of ponderosa pine and whitebark pine. Field data, however, shows that whitebark pine is always found above 5,000 feet elevation, and the ponderosa pine rarely occurs above that elevation. This provides us the opportunity to use a GIS data layer of elevation to stratify from the multi-spectral image, through an image "masking" technique, the "pine" spectral class

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Glen O. Klock is president of Western Resources Analysis, Wenatchee, WA.

into whitebark and ponderosa pine. If further stand type stratification was needed, additional GIS layers as required by the ecological model could be used for the purpose of stratification.

In 1983-84, the vegetation on the Okanogan National Forest was mapped using Landsat multispectral imagery (Klock and others 1984, 1985). This successful mapping project required the extensive use of ecological models to separate the many vegetative classes mapped in the project. Each of these ecological models was used to identify the area in which a species class might occur, and the imagery confirmed its presence or absence. The output vegetation map formed a GIS data layer.

More recent developments in GIS technology permit the generation of a new spatial data layer from an algebraic equation where the parameters are represented by other GIS data layers. Ecological models were used with the image "masking" technique to locate the many different map classes used in the Okanogan National Forest Landsat vegetative mapping project. This more recent algebraic ecological model technique development now simplifies and provides more flexibility in using GIS spatial data bases and models to map forest and range vegetation.

REFERENCES

Klock, G. O.; Jordan, L. E., III; Gum, P. 1984. An intensive LANDSAT inventory of high altitude vegetation for use in developing fire management strategies. In: Inventorying forest and other vegetation of the high latitude and high altitude regions: Proceedings of international symposium; 1984 July 23-26; Fairbanks, AK.

Klock, G. O.; Jordan, L. E., III; Gum, P. 1985. Developing a resource management data base for the Okanogan National Forest from multispectral imagery and the use of GIS. In: Remote sensing in forest and range resource management: Proceedings of PECORA-10; 1985 August 4-6; Fort Collins, CO: Colorado State University.

THE FIRE EFFECTS INFORMATION SYSTEM:

A COMPREHENSIVE VEGETATION KNOWLEDGE BASE

William C. Fischer

BSTRACT: The Fire Effects Information System, an uthoritative source of information on the effects f fire on plant and animal species, also includes comprehensive knowledge-base on biologic, cologic, economic, and distributional haracteristics of 141 plant species, 13 wildlife pecies, and one ecosystem. It could be a aluable tool for land managers and planners. A ersonal computer version is available. Editing o compile a plant and wildlife knowledge base pecific to a smaller unit, such as a National orest, is possible.

NTRODUCTION

his paper describes aspects of the Fire Effects nformation System developed by the Intermountain esearch Station, Forest Service, U.S. Department f Agriculture, in cooperation with Dr. Alden right, University of Montana Computer Science epartment. Simply stated, the Fire Effects nformation System is a computerized information torage and retrieval system. The particular mphasis of this paper is the vast informational ontent of the system's knowledge base and the use f vegetation classifications in that knowledge ase. The Fire Effects Information System was eveloped to be an authoritative, easy to access ource of information regarding the effect of orest and range fire (both wildfire and rescribed fire) on individual plant and animal ecies and on the plant communities in which ese species reside. To that end, comprehensive formation on physiologic, ecologic, stributional, economic, as well as fire effects aracteristics, had to be compiled.

e of the system, therefore, enables fire escriptions to be based on the best available formation and experience regarding the response target plant species to fire and how this sponse varies according to such factors as fire verity, season, phenological state, successional atus, site characteristics, and other biological and environmental considerations. Lack of organized, interpreted fire effects information, perceived by many managers as a barrier to the effective use of prescribed fire for vegetation management (Kickert and others 1976; Kilgore and Curtis 1987; Noste and Brown 1981; Taylor and others 1975), is no longer a valid excuse. There is plenty of information about fire effects in general and plant response to fire in particular, especially for the relatively few species of primary management concern.

BRIEF DESCRIPTION OF THE SYSTEM

The Fire Effects Information System is a computerized knowledge management system that stores and retrieves, in textual form, state-of-the-knowledge information organized in an encyclopedic fashion. It is, consequently, unlike most information systems available to natural resource managers and staff specialists. It is not a computerized bibliography (although a computerized bibliography is an important appendage to the system). It is not a numerical database although the system does accommodate numerical data.

For those abreast of computer science trends, the Fire Effects Information System is an object-oriented, frame-based, knowledge-based system implemented in the LISP programming language. The system was developed using concepts, methods, and techniques from the rapidly expanding field of artificial intelligence (AI). The application of AI in the design and structure of the system is described by Fischer and Wright (1987) and will not be repeated here. For a general overview of AI applications in natural resource management see Coulson and others (1987).

The Fire Effects Information System consists of three components: the knowledge base, the query program, and the builder program. The knowledge base represents the system's database. It contains the fire effects and related information that is available to users of the system. The query program allows access to the knowledge base, but does not allow any changes in the knowledge base. It is designed for people who are unskilled in the use of computers. The builder program is used by those who are adding to or editing the knowledge base. The user of the builder program is expected to be familiar with the structure of the knowledge base, and is expected to be skilled in the use of computers.

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per presented at the Symposium on Land assifications Based on Vegetation: Applications r Resource Management, Moscow, ID, November -19, 1987.

lliam C. Fischer is a Research Forester, termountain Research Station, Forest Service, S. Department of Agriculture, Missoula, MT.

THE KNOWLEDGE BASE

The Fire Effects Information System knowledge base is designed to accept information in three major categories: plant species, ecosystems, and wildlife species. The ecosystem category includes three levels of classification: an ecosystem level, a cover type level, and a habitat type or plant community level. For each category and level, the knowledge base contains state-of-knowledge information for various predetermined topics for several subject matter areas. Topics by subject matter area for each of the three categories of information are listed in tables 1-3. The knowledge base will accept information only for the predetermined topics listed in those tables. Addition of other topics is relatively simple for someone who is familiar with the structure of the system and capable of programming in the LISP language. Failure to make an entry in the knowledge base for a given topic has the effect of deleting that topic as far as a user of the query program is concerned. The topic title will not appear on the screen of the user's computer terminal unless an entry for that topic exists in the knowledge base. Fischer (1987) and Fischer and Wright (1987) provide examples of system output essentially as it would be displayed on the screen of a user's computer terminal.

Knowledge Base Development

The information contained in the knowledge base is the product of a rigorous process that includes (1) a thorough bibliographic search to identify literature related to the topics listed in tables 1-3, (2) obtaining hard copy of all such literature, (3) reading the literature, evaluating its reliability, and summarizing useful information, (4) resolving conflicts, if possible, between contradictory information, and (5) entering the information into the knowledge base. The research team responsible for knowledge base development to date is composed of professional biologists trained in the areas of botany,

Table 1--Plant species information by subject matter area contained in the Fire Effects Information System knowledge base

NOMENCLATURE AND TAXONOMY

Species name
Abbreviation
Synonyms
Common names
Taxonomy
Life form
Compiled by
Last revised by
References

DISTRIBUTION & OCCURRENCE

General distribution
Ecosystems States
Administrative units
BLM physiographic regions
Kuchler plant associations
SAF cover types
Habitat types
References

VALUE AND USE

Wood products value
Importance to livestock & wildlife
Palatability
Food value
Cover value
Value for rehabilitation of disturbed sites
Other uses and values
Management considerations
References

BOTANICAL & ECOLOGICAL CHARACTERISTICS

General botanical characteristics
Growth form
Raunkiaer life form
Grime plant strategy class
Grime regenerative strategy class
Regeneration processes
Site characteristics
Successional status
Seasonal development
References

PLANT ADAPTATIONS TO FIRE

General adaptations to fire
Lyon-Stickney survival strategy
Noble-Slatyer vital attributes
Rowe mode of persistence
References

FIRE EFFECTS

Fire effects on plant
Discussion & qualification
Plant response to fire
Discussion and qualification
References

FIRE CASE STUDY

Case study name
Reference
Season-severity class
Study location
Preburn vegetation
Target species phenological site description
Fire description
Fire effects on target species
Fire management implications

Table 2--Wildlife species information by subject matter area contained in the Fire Effects Information System knowledge base

NOMENCLATURE AND TAXOMONY

Species name
Abbreviation
Common name
Taxonomy
Order
Class
Compiled by
Last revised by
References

DISTRIBUTION & OCCURRENCE

General distribution
Ecosystems
States
Administrative units
BLM physiographis regions
Kuchler plant associations
SAF cover types
Plant communities
References

BIOLOGICAL DATA & HABITAT REQUIREMENTS

Timing of major life history events
Preferred habitat
Cover requirements
Food habits
Predators
References

FIRE EFFECTS & USE

Direct fire effects on animal
Habitat related fire effects
Fire use
References

wildlife biology, range science, and forestry. It takes, on the average, about 5 days for a team member to complete an initial species or ecosystem writeup and enter it into the knowledge base. Following entry into the knowledge base, the information for a given species or ecosystem is reproduced on paper and sent for technical review to scientists, staff specialists, and managers who have expert knowledge of the species or ecosystem. The information in the knowledge base is revised, as necessary, to reflect this technical review. Information in the knowledge base is periodically revised as necessary to incorporate new knowledge from current literature.

At this writing, the knowledge base contains information for 141 plant species (16 trees, 61 shrubs, 47 grasses, and 17 forbs), 13 wildlife species, and 1 ecosystem (sagebrush/grass). The Bureau of Land Management (BLM), U.S. Department of the Interior (USDI) supported development of the prototype knowledge base. A majority of the species included in the current knowledge base are those that frequent the sagebrush, pinyon-juniper, southwestern shrubsteppe, desert shrub, and chaparral-mountain shrub ecosystems described by Garrison and others (1977). Species occurring in other ecosystems and geographic areas can be added as funding allows. Recent cooperation with the National Park Service (NPS), USDI, to build a knowledge base for Wind Cave National Park, South Dakota, has resulted in addition of species occurring in the plains grasslands and Black Hills ponderosa pine forests of South Dakota. A list of species currently represented in the Fire Effects Information System knowledge base is included as an appendix to this paper.

Land and Vegetation Classifications

Land and vegetation classifications are important components of the information entered into the Fire Effects Information System knowledge base. Plant and wildlife species are classified according to their occurrence within categories of the following classifications:

- BLM Physiographic Regions (Bernard and Brown 1977),
- Forest-Range Environmental Study (FRES) ecosystems (Garrison and others 1977),
- Kuchler Potential Natural Vegetation Types (Kuchler 1964),
- Society of American Foresters (SAF) Forest Cover Types of the United States and Canada (Eyre 1980), and habitat types and plant community types.

Ecosystems included in the knowledge base will be those described in the Forest-Range Environmental Study (Garrison and others 1977). These soil-vegetation units represent aggregations of Kuchler's potential natural vegetation types. Ecosystem cover types are SAF cover types for forest ecosystems; shrub and grass cover types are designated according to dominant or codominant species. At the plant community or habitat type level, information is added to the knowledge base only when it differs significantly from similar information at the cover type level. Information at the plant community level may be for either individual habitat types or groups of habitat types that share common characteristics and have similar fire response.

Table 3--Ecosystem information by level and subject matter area contained in Fire Effects Information System knowledge base

ECOSYSTEM LEVEL

Ecosystem name
Classification key
FRES number
Kuchler vegetation types
Ecosystem distribution
References

PRODUCTIVITY

Characteristics/productivity classes
Dominant species/productivity classes
Potential production
References

CONDITION & TREND

Characteristics of condition classes
Indicators of trend
Qualification & discussion
References

FIRE ECOLOGY & EFFECTS

Fuels, flammability, & fire occurrence
General fire effects
References

COVER TYPE LEVEL

Cover type
Abbreviation
Classification key
Distribution
Site characteristics
Vegetative composition
Successional trends
References

VALUE & USE

Wood products
Livestock range
Wildlife habitat
Other values and uses
References

FIRE ECOLOGY & EFFECTS

Fuels, flammability, & fire occurrence
Immediate fire effects on site
Initial vegetative response
Long term vegetative response
Fire effects on grazing potential
Fire effects on wildlife habitat & populations
Fire use potential
References

PLANT COMMUNITY LEVEL

Community or group name
Abbreviation
Description
Community type composition
Distribution & occurrence
Site characteristics
Vegetative composition
Indicators of good condition
Indicators of poor condition
Productivity
Successional trends
References

MANAGEMENT CONSIDERATIONS

Wood products
Livestock range
Wildlife habitat
Other considerations
References

FIRE EFFECTS

Fuels, flammability, & fire occurrence
Initial community response
Long term community response
Fire effects on grazing potential
Fire effects on wildlife habitat and populations
Fire use potential
References
Fire case studies

Land and vegetation classifications are included in the knowledge base for several important reasons. Foremost is a simple recognition of the increasing use and reliance of these classifications in wildland management decisions at all levels. Classifications are also used because the descriptive data and interpreted information inherent in the classifications become attached to the classified unit, making repeated description and interpretation unnecessary (Nelson and others 1978). Finally, use of the classifications provides a basis for compiling smaller, special purpose knowledge bases from the main knowledge base. For example, SAF cover types (by State) could be used to compile a plant and wildlife species knowledge base specific to a National Forest.

Biological and Ecological Classifications

In addition to the land and vegetation classifications listed above, plant species are classified according to:

Growth Form,
Life Form (Raunkiaer 1934),
Plant Strategy (Grime 1979),
Regenerative Strategy (Grime 1979),
Survival Strategy (Lyon and Stickney 1976),
Vital Attributes (Noble and Slatyer 1977), and
Mode of Persistence (Rowe 1983).

These classifications, based on biological and ecological attributes, allow certain inferences related to the probable effect of fire on a plant species and subsequent plant species response to fire. While these classifications may provide useful information to those familiar with them, they are included primarily for research in the development of fire effects "expert systems." An expert system is a computer program designed to act as an expert in a particular area of knowledge (Mishkoff 1985). An expert system typically includes a knowledge base that contains both facts and rules of thumb through which the program searches to find a solution to a problem (Stock 1987). For more on expert system technology and an example of a forestry application see Rauscher and Cooney (1986).

CURRENT STATUS OF THE SYSTEM

The Fire Effects Information System, which was developed on a Digital Equipment Corporation (DEC) VAX 750 main frame computer at the University of Montana, now resides on a Data General (DG) MV 4000 computer at the Fire Sciences Laboratory in Missoula, MT. Current work includes such system enhancements as improving query program on-screen prompts, adding a print capability and improving knowledge base search and sort capabilities. Early this year the system was installed on a DG MV10000 computer at the Boise Interagency Fire Center for test and evaluation by BLM District and State Office personnel. In the near future, the system will be installed on a DEC VAX 750, also at Boise, for test and evaluation by NPS personnel. Test and evaluation of the system on one or more National Forests is planned for 1988. These tests and evaluations are of the query program and knowledge base only. The builder program resides only at the University of Montana and at the Intermountain Fire Sciences Laboratory. A personal computer (PC) version of the query program and knowledge base is available but a PC builder program is still being developed.

REFERENCES

Bernard, Stephen R.; Brown, Kenneth P. 1977. Distribution of mammals, reptiles, and amphibians by BLM Physiographic Regions and A. W. Kuchler's Associations for the eleven western States. Tech. Note 301. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 169 p.

Coulson, Robert N.; Folse, L. Joseph; Loh, Douglas K. 1987. Artificial intelligence and natural resource management. Science. 237: 262-267.

Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

Fischer, William C. 1987. The fire effects information system. In: proceedings, symposium on Wildland Fire 2000; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 128-135.

Fischer, William C.; Wright, Alden H. 1987. FIRESYS: using artificial intelligence techniques to build a fire effects information system. The Compiler. 5(5): 28-35.

Garrison, George A.; Bjugstad, Ardell J.; Duncan, Don A.; Lewis, Mont E.; Smith, Dixie R. 1977. Vegetation and environmental features of forest and range ecosystems. Agric. Handb. No. 475. Washington, DC: U.S. Department of Agriculture, Forest Service. 68 p.

Grime, J. P. 1979. Plant strategies and vegetation processes. Chichester, G. B.: John Wiley and Sons. 222 p.

Kickert, R. N.; Taylor, A. R.; Firmage, D. H.; Behan, M. J. 1976. Fire ecology research needs identified by research scientists and land managers. In: Proceedings, Tall Timbers fire ecology conference number 14; 1974 October 8-10; Missoula, MT. Tallahassee, FL: Tall Timbers Research Station and The Intermountain Fire Research Council: 61-91.

Kilgore, Bruce M.; Curtis, George A. 1987. Guide to understory burning in ponderosa pine-larch-fir forests in the Intermountain West. Gen. Tech. Rep. INT-233. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 39 p.

Kuchler, A. W. 1964. Manual to accompany the map: potential natural vegetation of the conterminous United States. Special Publication No. 36. New York: American Geographical Society. 149 p.

Lyon, L. Jack; Stickney, Peter F. 1976. Early vegetal succession following large Northern Rocky Mountain wildfires. In: Proceedings, Tall Timbers fire ecology conference number 14; 1974 October 8-10; Missoula, MT. Tallahassee, FL: Tall Timbers Research Station and The Intermountain Fire Research Council: 355-373.

Mishkoff, Henry C. 1985. Understanding artificial intelligence. Dallas, TX: Texas Instruments Incorporated. 258 p.

Nelson, D; Harris, G. A.; Hamilton, T. E. 1978. Land and resource classification-who cares? Journal of Forestry. 76(10): 644-646.

Noble, I. R.; Slatyer, R. O. 1977. Post-fire succession of plants in Mediterranean ecosystems. In: proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems; 1977 August 1-5; Palo Alto, CA. Gen. Tech. Rep. WO-3. Washington, DC: U.S. Department of Agriculture, Forest Service: 27-36.

Noste, Nonan V.; Brown, James K. 1981. Current practices of prescribed burning in the West. In: Proceedings, 1981 John S. Wright forestry conference, Weed control in forest management; 1981 February 3-5; West Lafayette, IN. West Lafayette, IN: Purdue University, Department of Forestry and Natural Resources: 156-169.

Raunkiaer, C. 1934. The life form of plants and statistical plant geography. Oxford: Clarendon Press. 632 p.

Rauscher, H. M.; Cooney, T. M. 1986. Using expert system technology in a forestry application: the CHAMPS experience. Journal of Forestry. 84(3): 14-17.

Rowe, J.S. 1983. Concepts of fire effects on plant individuals and species. In: Wein, Ross W.; MacLean, David A. eds. The role of fire in northern circumpolar ecosystems. SCOPE Report Number 18. New York: John Wiley and Sons: 135-154.

Stock, Molly. 1987. AI and expert systems: an overview. AI Applications in Natural Resource Management. 1(1): 9-17.

Taylor, A. R.; Kickert, R. N.; Firmage, D. H.; Behan, M. J. 1975. Fire ecology questions survey. Gen. Tech. Rep. INT-18. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

APPENDIX

Plant And Animal Species Currently Represented In The Fire Effects Information System Knowledge Base

Tree Species

Cercocarpus ledifolius, curlleaf mountain-mahogany
Cercocarpus montanus, true mountain-mahogany
Juniperus occidentalis, western juniper
Juniperus osteosperma, Utah juniper
Juniperus scopulorum, Rocky Mountain juniper
Pinus albicaulis, whitebark pine
Pinus aristata, Rocky Mountain bristlecone pine
Pinus balfouriana, foxtail pine
Pinus edulis, pinyon
Pinus flexilis, limber pine
Pinus longaeva, Great Basin bristlecone pine
Prunus monophylla, singleleaf pinyon
Prunus americana, American Plum
Prunus pennsylvanica, pin cherry
Prunus virginiana, chokecherry
Rhus glabra, smooth sumac

Shrub Species

Amelanchier alnifolia, Saskatoon serviceberry
Amelanchier utahensis, Utah serviceberry
Artemisia arbuscula ssp. arbuscula, gray low sagebrush
Artemisia arbuscula ssp. thermopola, hotsprings sagebrush
Artemisia argillosa, coaltown sagebrush
Artemisia bigelovii, Bigelow sagebrush
Artemisia cana ssp. viscidula, mountain silver sagebrush
Artemisia cana ssp. bolanderi, Bolander silver sagebrush
Artemisia cana ssp. cana, plains silver sagebrush
Artemisia filifolia, sandsage or sand sagebrush
Artemisia frigida, fringed sagebrush
Artemisia longiloba, early or alkali sagebrush
Artemisia nova, black sagebrush
Artemisia papposa, fuzzy sagebrush
Artemisia pedatifida, birdfoot sagebrush
Artemisia pygmaea, pygmy sagebrush
Artemisia rigida, stiff or scabland sagebrush
Artemisia spinescens, budsage or bud sagebrush
Artemisia tridentata ssp. tridentata, basin big sagebrush
Artemisia tridentata ssp. vaseyana, mountain big sagebrush
Artemisia tridentata ssp. wyomingensis, Wyoming big sagebrush
Artemisia tripartita ssp. rupicola, Wyoming threetip sagebrush
Artemisia tripartita ssp. tripartita, tall threetip sagebrush
Atriplex canescens, four-wing saltbrush
Atriplex confertifolia, shadscale
Atriplex gardneri, saltsage
Ceratoides lanata, winterfat
Chrysothamnus nauseosus, grey rabbitbrush
Chrysothamnus viscidiflorus, green rabbitbrush
Cowania mexicana ssp. stansburiana, Stansbury cliffrose

Ephedra nevadensis, Nevada ephedra
Ephedra viridis, green ephedra
Grayia brandegei, spineless hopsage
Grayia spinosa, spiny hopsage
Gutierrezia sarothrae, broom snakeweed
Holidiscus discolor, oceanspray
Holidiscus dumosus, bush oceanspray
Opuntia polyacantha, plains prickly pear
Potentilla fruticosa, shrubby cinquefoil
Potentilla newberryi, cinquefoil
Prunus andersoni, desert peach
Purshia glandulosa, desert bitterbrush
Purshia tridentata, antelope bitterbrush
Rhus aromatica, fragrant sumac
Rhus trilobata, skunkbrush sumac
Ribes americanum, American black currant
Ribes aureum, golden currant
Ribes cereum, wax currant

Ribes lacustre, swamp currant
Ribes montigenum, gooseberry currant
Ribes odoratum, buffalo currant
Ribes setosum, bristley currant
Ribes velutinum, desert gooseberry
Sarcobatus baileyi, Bailey greasewood
Sarcobatus vermiculatus, black greasewood
Symphoricarpos longiflorus, Longfellow snowberry
Symphoricarpos oreophilus, mountain snowberry
Tetradymia canescens, spineless horsebrush
Tetradymia glabrata, littleleaf horsebrush
Tetradymia nuttallii, Nuttall horsebrush
Tetradymia spinosa, spiny horsebrush

Graminoid Species

Aristida purpurea (*A. longiseta*), three-awn grass
Bouteloua curtipendula, sideoats grama
Bouteloua eriopoda, black grama
Bouteloua gracilis, blue grama
Bouteloua hirsuta, hairy grama
Bromus carinatus, California brome
Bromus inermis, smooth brome
Bromus japonicus, Japanese brome
Bromus marginatus, mountain brome
Bromus mollis, soft chess
Bromus rubens, red brome
Bromus tectorum, cheatgrass or downy brome
Buchloe dactyloides, buffalograss
Danthonia intermedia, timber oatgrass
Danthonia spicata, poverty oatgrass
Danthonia unispicata, onespike oatgrass
Elymus canadensis, Canada wildrye
Elymus elymoides, (*Sitanion hystrix*), bottlebrush squirreltail
Elymus glaucus, (*E. virescens*), blue wildrye
Elymus lanceolatus, (*Agropyron dasystachyum*, *A. elmeri*, *A. riparium*), thickspike wheatgrass
Festuca idahoensis, Idaho fescue
Festuca scabrella, rough fescue
Festuca thurberi, Thurber fescue
Hilaria jamesii, big galleta
Hilaria rigida, galleta
Koeleria cristata, prairie junegrass
Leucopoa kingii, spike fescue
Leymus (*Elymus*) *ambiguus*, Colorado wildrye
Leymus (*Elymus*) *cinereus*, basin wildrye
Leymus (*Elymus*) *salinus*, Salina wildrye

Oryzopsis hymenoides, Indian ricegrass
Pascopyrum (*Agropyron*) *smithii*, western wheatgrass
Poa cusickii, Cusick bluegrass
Poa arida, plains bluegrass
Poa fendleriana, mutton bluegrass
Poa secunda, (*P. ampla*, *P. canbyi*, *P. juncifolia*, *P. nevadensis*, *P. sandbergii*), Sandberg bluegrass
Psathyrostachys juncea (*Elymus junceus*), Russian wildrye
Pseudoroegneria spicata (*Agropyron spicatum*, *A. inerme*), bluebunch wheatgrass
Stipa comata, needle-and-thread grass
Stipa columbiana, Columbia needlegrass
Stipa lettermanii, Letterman needlegrass
Stipa thurberiana, Thurber needlegrass
Stipa viridula, green needlegrass
Taeniatherum caput-medusae, medusahead
Vulpia (*Festuca*) *microstachys*, small fescue
Vulpia myuros (*Festuca megalura*), foxtail fescue
Vulpia (*Festuca*) *octoflora*, six-weeks fescue

Forb Species

Achillea millefolium, common yarrow
Artemisa abrotanum, oldman sagebrush, oldman wormwood
Artemisa camprestris, sagewort wormwood, western sagebrush
Artemisia dracunculus, tarragon
Artemisia ludoviciania, Louisiana sagewort
Balsamorhiza hookeri, hairy balsamroot
Balsamorhiza sagitata, arrowleaf balsamroot
Centaurea diffusa, tumble knapweed
Centaurea maculosa, spotted knapweed
Centaurea solstitialis, yellow starthistle
Descurainia pinnata, tansymustard
Descurainia sophia, flixweed tansymustard
Potentilla glandulosa, sticky cinquefoil
Potentilla hippiana, horse cinquefoil
Ranunculus glaberrimus, sagebrush buttercup
Sisymbrium altissimum, tumble mustard
Sisymbrium linifolium, flaxleaf plains mustard

Wildlife Species

Amphibians & Reptiles

Ambystoma macrodactylum ssp. *krausei*, northern long-toed salamander
Crotalus viridis, western rattlesnake
Sceloporus graciosus, sagebrush lizard
Scophiopus intermontanus, Great Basin spadefoot toad

Birds

Aquila chrysaetos, golden eagle
Athene cunicularia, Burrowing owl
Buteo regalis, ferruginous hawk
Centrocercus urophasianus, Sage grouse
Falco mexicanus, praire falcon

Mammals

Antilocapra americana, pronghorn antelope
Lepus californicus, black-tailed jack rabbit
Perognathus parvus, Great Basin pocket mouse
Spermophilus townsendii, Townsend's ground squirrel

GIS DATABASE DESIGN FOR INDUSTRIAL FOREST MANAGEMENT

Dennis L. Murphy

ABSTRACT: Industrial forest management requires accurate map and attribute information to support timber management. Geographic information system (GIS) technology integrates the storage, retrieval, and analysis of both map and attribute data. Database design methodologies structure data in order to model the activities of an organization. A design methodology guides the search for a suitable design. The method (1) identifies critical data, (2) classifies the data into layers, map features, and attributes, and (3) expresses the design in data definition statements. A geographic database design for an in-place forest management inventory provides an example for similar design efforts.

INTRODUCTION

Management of a commercial forest in a highly competitive industry requires the forest manager to respond to changing market conditions. The manager relies upon inventory information to prepare and modify plans and budgets, which guide forest operations. The inventory information describes timber volumes at specific locations. Intensive forest inventories provide the data to support the manager's information requirements. Specifically, the intensive (or in-place) inventory addresses two fundamental forest management questions: "What volume of end products is available for harvest?", and "Where is the volume located?"

The in-place inventories collect tree measurements from which volumes are derived. Timber stands define the sampling unit for the in-place inventory. By delineating these discrete polygons on a base map, the forester not only records the management unit, but also defines the boundaries from which stand area is measured. The stand area expands the inventory sample estimates to total stand estimates of volume. Stand level summaries can be further aggregated to report by larger administrative units.

Effective management of the inventory database to facilitate storage, retrieval, and analysis is necessary in order to realize the potential benefits of the investment. Particularly for forest management organizations with large land holdings, manual record storage methods are no longer practical. The combination of a digital attribute database with a traditional paper map file is also ineffective. The discipline of geographic information systems provides the technology to effectively manage a forest inventory database consisting of detailed map information and site-specific stand attributes.

An important task in the implementation of a geographic information system is the design of the integrated map and attribute database. As part of the software system, a GIS provides the basic structure for data storage; within the structure, the user designs a database for the specific application.

The design considerations to a new system user are not always evident. Each organization that implements these systems addresses similar design problems. Unfortunately, few system application designers have documented the results of their efforts for the benefit of others. The purpose of this paper is to describe the design of the integrated resource inventory database implemented for Potlatch Corporation, Western Wood Products Division, Lewiston, ID. Although the resulting design is specific to the Potlatch Corporation inventory cruise system and the data model supported by a commercially available GIS, the results have general benefit to other forestry organizations addressing GIS database design issues.

COMPONENTS OF THE IN-PLACE FOREST INVENTORY

Stand Delineation

The timber stand is the primary map feature of the in-place inventory. The following factors are considered in the delineation of a stand:

1. Size: 10-acre minimum (average size is 150 acres).
2. Single management prescription: Can the bounded area be treated by one management prescription?
3. Operability: Is it feasible to complete the prescribed management activity within one planning period?
4. Sampling unit: Is the variability within the boundary relatively small?

Note that the phototype is not a consideration in stand delineation. In contrast to inventory sample designs based upon a stratification of vegetation types delineated from aerial photography, the in-place cruise defines each individual stand as a separate sample unit. The stand may contain a single phototype but frequently is a collection of similar phototypes. The stands

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Dennis L. Murphy is GIS Supervisor, Potlatch Corporation, Lewiston, ID.

delineated under an in-place inventory system tend to be larger than the stands mapped from an inventory designed with a stratified sample of vegetation phototypes.

Other map features that influence stand delineation include public land survey lines, ridges, streams, and roads. Public land survey defines the ownership for the organization. All stands are contained within the mapped ownership. The accuracy of the ownership can significantly alter the stand acres estimate. Planimetric features (ridge lines, streams, and roads) are also frequently used as boundaries between stands. The planimetric features represent breaks in terrain conditions.

The forester assigns a unique number to the delineated stand. The unique identifier is an hierarchical key--the key identifies three spatially nested administrative units: logging unit, management block, and stand.

tand Attributes

Within the stand boundary, an intensive cruise stablishes plot locations at an average density f one plot per five acres. Tree measurements are ollected at the plot locations. Field personnel record stand level characteristics and assign anagement prescriptions as part of the cruise rocedure.

he tree measurements collected from the plots within each stand are the source for stand tables pecific to the stand polygon. The stand table is tabulation of trees per acre by species and iameter class. From the stand table characterstics, average volumes per acre are estimated for end products using current log merchandising specifications. The merchandised stand tables are further summarized to derive stand level attributes.

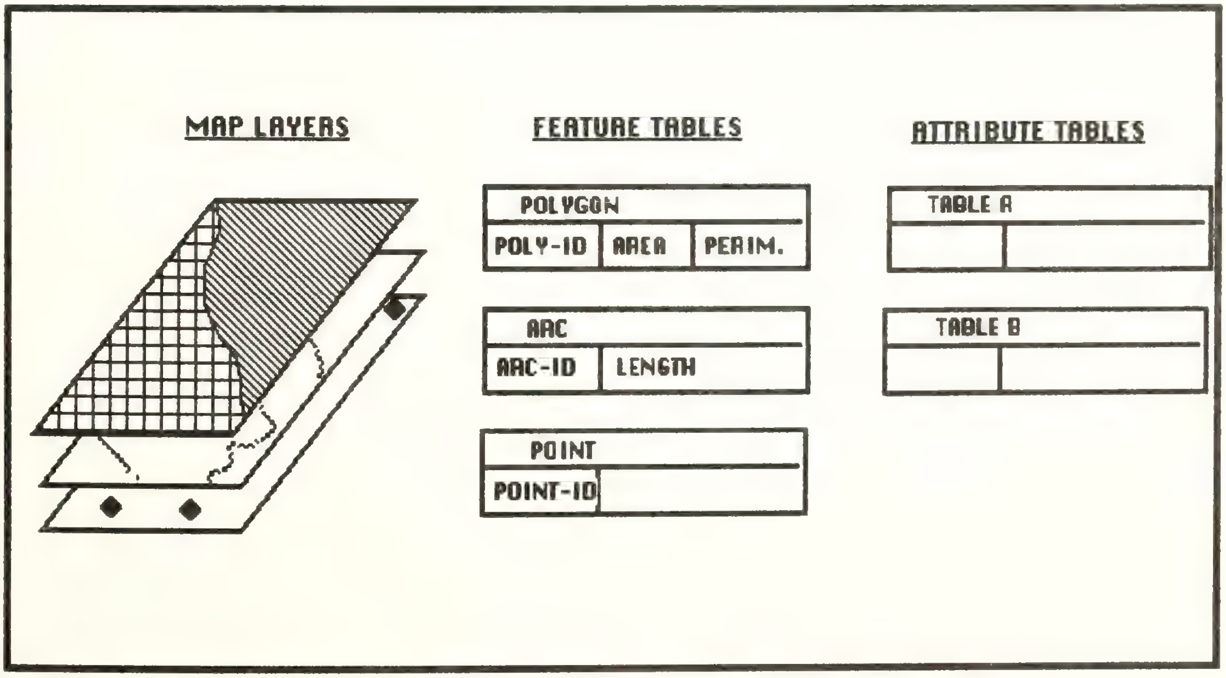
The map features and the stand level attributes are managed as an integrated resource inventory database. A GIS integrates the database components into a single system. In order to manage this dynamic database, the data elements have been structured using a GIS data model described in the section below.

DATA MODEL

The ARC/INFO GIS software (ESRI 1987) incorporates a topological-relational data model. The data model components include map layers, map feature tables, attribute tables, and relationships between them (fig. 1). Map layers are stored as groups of data files containing the coordinate data for the map features. Two types of tables are available in the model to store attribute data: map feature tables and attribute tables. The software creates map feature tables when the map layer data files are processed by edit utilities. Depending upon the type of map feature stored in the map layer, different attributes are automatically included. Map feature types are polygon, line (arc), and point.

A polygon layer always includes a polygon feature table, which stores the area and perimeter of the polygon. At the user's discretion, the polygon layer may also create an arc feature table. The arc feature table can be used to classify the lines which define the polygon boundaries.

An arc layer includes an arc feature table, which stores the length of each arc in the file.



igure 1--Topological-relational data model.

Point feature tables are created when a point layer is processed. No spatial attributes are stored in the point feature table.

All feature tables store internal identifiers assigned by the software to relate the tables to the spatial (coordinate) data. At the user's discretion, additional attributes may be defined and stored in the feature tables.

The user's database design may also include attribute tables, which are stored separately from the map feature tables. Through the use of a common item, the feature tables may be directly related to the attribute tables and thereby indirectly link the attribute tables to the map features for retrieval and display. Separating the attributes from the feature tables reduces redundant data storage and facilitates the update of map and attribute data as separate system processes.

Data Model Definition

To describe the database design, a data model syntax will be employed to define the database structure implemented for the in-place forest inventory. The definition statements will follow the convention described below:

```
[LAYER] <TABLE:ATTRIBUTE(KEY | RELATE ITEM |
               CLASS/CLASS VALUES/);>
```

Layer is the name of the collection of files storing map features. The layer name is enclosed by brackets.

Each layer has at least one table stored in a relational database management system. The table name follows the symbol "<". By convention, the map feature tables for the a layer are named polygon, arc, or point, depending upon the feature type of the map layer. The attribute names contained in the table follow the colon.

Attributes may be designated in the definition as a key, a relate item, a class item, or the attribute may have no special designation. The specially designated items are identified in the database definition with the appropriate word contained within parentheses following the attribute name, for example, STAND(KEY).

A key attribute uniquely identifies attributes for a specific map feature. By adding a key item to a map feature table, the user provides a link to other attribute tables for retrieval, reporting, and display functions.

A relate attribute also relates records in other tables with the same value for the common attribute between the tables; it is differentiated from a key attribute because the related attributes are not unique for the map feature. Other map features share the same value of the attribute, in contrast to the key which uniquely identifies the attributes for one map feature.

A class attribute can be stored in a feature table to distinguish between categories of map features stored in the same map layer. For example, road classes are stored in a map layer; a class attribute records the appropriate category for each road segment. One application of the class attribute is the assignment of cartographic symbols for map display.

In the definition syntax, the possible class values appear between slashes, "/". The definition of an attribute table terminates with the right caret symbol, ">".

The database definition statements for the in-place forest inventory are listed below.

Forest Layer

```
[FOREST] <POLYGON:STAND(KEY);AREA;PERIMETER>

     <ARC:ARC-ID(CLASS/LOGGING UNIT/MANAGEMENT
           BLOCK/STAND);LENGTH>

     <MANAGE:STAND(KEY);TREATMENT;PRIORITY;
           HARVEST PLAN STATUS;PERCENT OF
               STAND TREATED>

     <SITE:STAND(KEY);HABITAT TYPE;PHYSICAL
            SITE INDEX;TREE SITE INDEX;
            PHOTOTYPE;AGE STRUCTURE;DOMINANT
            AGE;SECONDARY AGE;ELEVATION;SLOPE;
            ASPECT;SOIL DEPTH;SOIL TEXTURE>

     <VOLUME:STAND(KEY);GROSS SAWLOG;TOTAL NET
            SAWLOG;STEMS PER ACRE;CROWN RATIO;
            QUADRATIC MEAN DIAMETER;BASAL AREA;
            CROWN COMPETITION FACTOR>
```

The primary map feature of the in-place inventory is the stand; the stand is uniquely identified with an attribute that is a concatenated key. The map layer actually contains three administrative units that are nested polygons: logging units (approximately 15,000 acres each), management blocks (1,000-2,000 acres), and stand (average size 150 acres). Since the administrative units represent a spatial hierarchy, all three are represented by the concatenated key stored as a key attribute named STAND.

The key is stored in the polygon feature table and also in the stand attribute tables MANAGE, SITE, and VOLUME.

The stand layer also has an arc feature table; the attribute ARC-ID is a class attribute which identifies polygon boundaries by the management unit they define.

Legal Parcel Layer

```
[PARCEL]  <POLYGON:PARCEL-ID(KEY);DEED
          NUMBER(RELATE ITEM);OWNER(CLASS/
          POTLATCH/U.S. FOREST SERVICE/
          BUREAU OF LAND MANAGEMENT/IDAHO
          DEPARTMENT OF LANDS/PRIVATE);AREA;
          PERIMETER>

     <ARC:ARC-ID(CLASS/TOWNSHIP/SECTION/
          INTERIOR LINE);LENGTH>
```

Land ownership defines external stand boundaries. No stand crosses an ownership boundary. The legal parcel layer contains the individual parcels recorded by deed as a land transaction. The polygon table incorporates a unique key for each parcel. Similar to the stand, the legal parcel is a concatenated key representing a hierarchy of nested public land survey polygons: township, section, and legal parcel. A deed number, stored in the POLYGON feature table, serves as a relate item to a land record database (these additional attribute tables are not further described because they are not directly a part of the in-place inventory). A class attribute, OWNER, identifies the current land owner of the parcel.

An arc feature table uses a class attribute, ARC-ID, to distinguish between the township, section, and parcel boundaries.

Baseline Layer

[BASELINE] <ARC:ARC-ID(CLASS/RIDGE/CLIFF/DOUBLE LINE HYDROLOGY/MAJOR STREAM/MINOR STREAM/LAKE);LENGTH>

Streams, rivers, and ridges contribute to the delineation of stand boundaries. These features are stored as arcs with a feature table that has a class attribute (ARC-ID). The class attribute differentiates the linear features stored in the layer; in addition, map symbology assigned for display and plotting references the values of the class attribute.

Road Layer

[ROAD] <ARC:ARC-ID(CLASS/PAVED/PRIMARY/SECONDARY/TRAIL);LENGTH>

The road layer has one feature table with a class attribute for different types of roads. The roads are obviously the transportation network for the Forest; they also frequently define a portion of the stand boundary.

Basepoint Layer

BASEPOINT] <POINT:POINT-ID(CLASS/STATE PLANE TIC/PEAK/SADDLE/SURVEY CORNER)>

The basepoint layer contains essential features or locational reference and for the development of all other map layers. The POINT feature table ncludes a class attribute that distinguishes the ifferent types of point features stored in the ap layer. The state plane coordinate system grid ic locations were the geographic reference for ll map layers. Every map feature was registered o the Idaho State Plane coordinate system. These oint features are stored in the BASEPOINT layer. urvey corners are also included in the layer. hile the state plane tic marks provide the proected coordinate reference for the map database, he survey corners define the reference points for he public land survey and the legal parcels.

Legal parcels are referenced by public land survey descriptions, as well as coordinate descriptions. Both referencing conventions are essential to the map database.

Other Layers

Applications of the system have and will involve other map layers. Historical information tracking silvicultural and harvest activities is an example. However, this paper limits the discussion to the basic map layers essential to maintain the in-place forest inventory.

RETRIEVAL/ANALYSIS

The integrated storage of the map and attribute data facilitates data retrieval, reporting, and map display. Stands can be selected and displayed with selection criteria based on any of the attributes stored in the tables. The relationship established by the key attribute provides the mechanism. For example, the following selections are possible combining attribute selection criteria from several tables:

1. Map stands that are in a current harvest plan, dominant age greater than 80 years, and net sawlog volume exceeds 5 million board feet per acre.

2. Report total stand volume, stand acres, and harvest priority for the selected stands.

Derived Layers

Spatial relationships within and between map layers provide an analytical capability of the integrated database. The spatial relationships derive new map layers with feature tables containing the attributes of the original map layer feature tables. Spatial analysis functions include: combining map layers, creating buffer zones, and proximity (distance) functions. Polygon map layers can be combined as the union, intersection, or complement of two layers. Also, line and polygon overlays, as well as point in polygon overlays, create new map layers. Proximity functions measure the nearness of a map feature to a second type of map feature.

For example, the analytical capabilities can estimate the area of stands impacted by riparian zone management constraints. The steps and layers derived are summarized below:

1. Select Class I streams and generate a buffer zone of a specified width from the stream centerline. The derived layer is described as follows.

[BUFFER] <POLYGON:ZONE(CLASS/INSIDE BUFFER/OUTSIDE BUFFER/);AREA;PERIMETER>

2. Create the union of the FOREST and BUFFER layers, deriving the layer STAND-ZONE.

```
[STAND-ZONE] <POLYGON:STAND(KEY);ZONE(CLASS/INSIDE
             BUFFER;OUTSIDE BUFFER/);AREA;PERIMETER>
```

The layer named STAND-ZONE contains the information in the feature table to summarize the acres by stand within the buffer zone. Note also that as a result of the map overlay, the key attribute (STAND) is included in the POLYGON feature table for the derived layer. Thus, all attributes in the tables SITE, MANAGE, and VOLUME automatically have a relationship to the STAND-ZONE POLYGON feature table through the key attribute. The stand per-acre estimates of volume can be expanded by the acres in the buffer zone to estimate the volume impacted by the riparian zone management.

At the user's option, the derived layers may be added to the database as a permanent layer or further processed with analysis functions.

IMPLICATIONS FOR HABITAT MAPPING

The growth of GIS technology has been accompanied by the expansion of Federal and State programs, which produce digital geographic data for a variety of users. The U.S. Geological Survey's digital files of elevation (digital elevation models), map features (digital line graphs), and satellite imagery are examples. The USDA Soil Conservation Service is digitizing soil type maps. The potential exists to produce and distribute land classification data in digital form to a variety of resource management organizations.

Application of habitat classification methods produces maps and tables of attributes for discrete polygons. GIS technology, the ability to integrate map and attribute data, has potential applications to the management of data for land classifications. How might this information be structured in a geographic database? Two alternatives can be represented as database design options, employing the data definition syntax applied above to the in-place forest inventory.

The first alternative is to manage a database of habitat maps and attribute tables. The GIS could then be used to manage the data and produce either paper products or digital files for users of the information. The layer is described as follows:

```
[HABITAT] <POLYGON:HABITAT-TYPE(RELATE ITEM);
                AREA;PERIMETER>

          <CHARACTERISTICS:HABITAT-TYPE;
              ATTRIBUTE1..ATTRIBUTEn>
```

A second alternative is to maintain a database of source information from which habitat type maps would be derived. The analytical functions of the geographic information system would be applied in this alternative to derive the habitat types based upon spatial relationships between the source map layers. An example of a database structured in this fashion is as follows:

```
[LAND COVER]    <POLYGON:VEGETATION(RELATE ITEM);
                     AREA;PERIMETER>

                <COVER-TYPE:VEGETATION;ATTRIBUTE1..
                     ATTRIBUTEn>

[ELEVATION]     <POINT:ELEVATION>

[SLOPE]         <POLYGON:SLOPE-CODE(CLASS)/CLASS1..
                     CLASSn/;AREA;PERIMETER>

[ASPECT]        <POLYGON:ASPECT-CODE(CLASS)/CLASS1..
                     CLASSn/;AREA:PERIMETER>

[SOIL]          <POLYGON:SOIL-CODE(RELATE ITEM);
                     AREA;PERIMETER>

                <SOIL-TYPE:SOIL-CODE;ATTRIBUTE1..
                     ATTRIBUTEn>
```

As a point layer, elevation can be manipulated to produce the slope and aspect layers specifying the class intervals at the time the layers are derived. In addition, elevation point data can be modified to produce a polygon layer of elevation, with elevation intervals specified by the user. A union of the five polygon layers (elevation, slope, aspect, land cover, and soils) would result in a map layer of polygons, which represent the lowest common denominator between the original map layers.

The second database design alternative has major benefits if the individual map layers can be developed. The user has more flexibility with the separate map layers. If one layer changes due to new information, the new layer replaces the old. The derived habitat layer can be reprocessed. An example is the replacement of a general soil survey by a higher resolution survey not previously available. The derived habitat layer can be recreated using the new soils layer. In addition, the multi-layer approach provides the end data user with the capability to customize the derived layer by specifying the classification "rules" to follow.

By maintaining the original resolution of the map layers and attributes, alternative habitat type layers can be derived for organizations with differing resource management objectives. If the original database design takes full advantage of the data model to specify map feature keys, relate attributes, and class attributes, the system can provide the flexibility to produce map and tabular reports from the source data to satisfy a variety of users with requirements specific to their organization.

CONCLUSIONS

The in-place inventory represents a substantial investment by a forestry organization. The level of effort to collect the information is not justifiable if the end product is single map and corresponding table. The benefit of an integrated geographic database is the expanded capability to derive map and tabular products from the relationships established by the data model or derived from analytical functions applied to the model. With the proper design effort, the database can be updated to meet operations requirements for current data.

In a similar manner, land classification studies represent a substantial data collection and analysis effort. Intensive field data collection techniques result in maps and attributes describing land characteristics. The utility of this information would be extended by developing an integrated geographic database designed with fundamental map layers, feature tables, and attribute tables. By designing the database with the objective of deriving the land classification from source layers, the database will provide more flexibility for resource managers to derive digital and paper products customized for their specific requirements. In addition, the database design will accommodate changes in source map layers when information of higher quality becomes available.

The technology is available to manage integrated resource databases of map and attribute information. Land classification research and applications produce both map and tabular data. The utility of this information can be extended with today's geographic information system technology.

REFERENCE

ESRI. 1987. Users Guide: ARC/INFO. Volume 1. Redlands, CA: Environmental Systems Research Institute.

HABITAT TYPES ARE A TOOL FOR PRESCRIBING STAND TREATMENT

Milo J. Larson

ABSTRACT: Habitat types provide silviculturists an improved basis for prescribing stand treatments. The method is widely accepted and its advantages include ease of application and much-improved results from silvicultural applications.

INTRODUCTION

Habitat types are the land area that will support an identifiable plant association once plant succession progresses to its latest stages. They are usually identified in the field by key indicator plants that are present in the life of a stand (Daubenmire and Daubenmire 1968).

Habitat types have filled an information gap that has heretofore been met by a trial-and-error process known as experience. Silvicultural experience was extremely localized and the opportunity to learn from others in other areas was hampered by glaring inconsistencies in results that could not be readily explained.

The major advantage of habitat types is that they reflect a range of environmental conditions. This range is much narrower than the range of conditions identified with an individual tree species or cover type. Consequently, silvicultural implications for a given treatment can be much more closely refined than ever before.

When a habitat type (or plant association) classification is completed for an area, every acre of the forest can be readily identified to a set of environmental conditions. The individual types are readily identifiable so that they can be recognized by virtually any trained individual without special equipment or an advanced education. Even without a substantial mapping effort, useful conclusions about any given stand can readily be reached.

USE IN SILVICULTURE

Some basic silvicultural applications that are important include reforestation, harvest prescriptions, assessing site quality, rating pest susceptibility, choice of tree species to favor in management, and prediction of plant communities that will result from the application of a treatment. The number of ways habitat types can be used to improve silvicultural decision making is almost infinite, and is limited only by the intuition of the individual making the prescription.

The major advantage lies in providing a framework for the experience and insight we already have to a stand that lies somewhere in the range of environments occupied by the species being managed. Examples may illustrate:

Lodgepole pine (Pinus contorta) grows on more than 100 habitat types (Alexander 1985); a small list of about 10 or so may occur on a Ranger District where lodgepole occurs. What do the habitat types tell us that lodgepole pine types or community type do not? Consider lodgepole pine growing on a warm moist habitat type such as western redcedar/pachistima (Thuja plicata/Pachistima myrsinites). The silvicultural implications include a relatively good site, a relatively short pathological rotation for lodgepole pine, a variety of associated species that can be grown there, and a good potential for luxuriant shrub or forb stands following disturbance.

In the same general area, a lodgepole pine stand may grow on a cold, moist habitat type such as mountain hemlock/rusty menziesia (Tsuga mertensiana/Menziesia ferruginea) habitat type. In this stand, site index will probably be lower, the list of associated species will be much shorter and include plant and animal species not common on the warmer habitat type. Regeneration problems associated with snow mold, snow bend, cold nights, and short summers also come to mind.

The difference in response of both plants and animals to a given treatment such as a clearcut will be dramatic on these moist but very different sites.

REGENERATION

An early and perhaps the most crucial application of habitat types was in reforestation prescriptions. Several aspects of regeneration of tree stands have been improved.

Successional Status

Recognition of the successional status of tree species within a habitat type greatly improved reforestation success. Before habitat types came along in the late 1960's, foresters typically planted the species that were cut. For example,

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Milo J. Larson is a Forester with the U.S. Department of Agriculture, Forest Service, Washington, DC.

Douglas-fir (Pseudotsuga menziesii) and grand fir (Abies grandis) stands were clearcut and replanted. They often failed to do well on habitat types where ponderosa pine (Pinus ponderosa) or lodgepole pine would have clearly been better performers in early seral stages. This has been attributed to near-the-ground frost or day-to-night temperature extremes (Larson 1977). Errors were also made at the other end of the ecological scale such as when ponderosa pine was observed to grow well on many sites where grand fir or white fir (Abies concolor) grew. Thus, the assumption was made that it would do well every place white fir or grand fir grew. Many failures resulted because some habitat types that support grand fir or white fir are too cold for ponderosa pine to grow well even though many of the warmer fir habitat types are very favorable.

Probability of Seedling Survival

The plants that grow on the various habitat types indicate the range of environmental conditions from warm to cold and dry to wet. The coldest, the warmest, the wettest, and the driest habitat types are often easily recognized and can be predicted to be difficult for seedling establishment regardless of successional status of the species chosen. These simple observations can and should influence choice of regeneration method or even the suitability of land for production of timber.

Natural Regeneration

The most complex and interesting aspect of habitat types is that choice of regeneration method and degree of canopy opening control, to a large extent, the species composition of the new stand. It varies by habitat type but is predictable with a reasonable degree of reliability for a given area (USDA Forest Service 1985). One brief example is the subalpine fir/twin flower (Abies lasiocarpa/Linnaea borealis) habitat type. On this and similar habitat types, selection and light multistep shelterwood cuts favor subalpine fir (Abies lasiocarpa), two cut shelterwoods with a heavy seed cut tend to favor Engelmann spruce (Picea engelmannii) or lodgepole pine. These rather profound effects are often overlooked by silviculturists, managers, forest planning models, and the general public, all of whom may expect that spruce regeneration will result regardless of the regeneration method chosen.

The dozens of species, hundreds of habitat types and response to the various silvicultural systems are the heart and soul of silvicultural expertise in areas where natural regeneration is the desired goal.

Competing Vegetation

Lack of knowledge of response of nontree vegetation has caused some expensive and serious errors in reforestation.

For example, there are a large number of forest habitat types with understories of shade-loving forbs. These plants typically perish upon stand opening and the more seriously competitive grasses and sedges invade over a several year period. Prompt reforestation without substantial site preparation is the best choice on these sites. Other habitat types have understories comprised of intensively competitive shrubs, grasses, or sedges that respond vigorously and promptly to stand opening. Here the prescriptions must provide for adequate site preparation.

Choice of site preparation should also be influenced by the habitat type. For example, burning is a good site preparation method on many habitat types, but on several it does not favor regeneration of conifers, notably those with oak (Quercus spp.) understory unions and high-elevation subalpine fir habitat types (USDA Forest Service 1986).

Knowing habitat type in advance of the timber harvest is the key to avoiding unnecessary problems or expense.

PEST MANAGEMENT

Because habitat types can be used to predict environment, they sometimes can be used to predict a range of conditions adverse or favorable to a certain pest. An example is that some habitat types that support host tree species for western spruce budworm are too cold to support epidemic outbreaks of the insect.

Although many relationships between habitat types and pest populations probably exist, a great deal more research will be necessary to identify them.

Site Quality

Habitat type is the primary variable for predicting productivity in the Stand Prognosis Model (Stage 1973). It is also used for estimating site quality in silvicultural decision making (Steele and others 1983). Each habitat type reflects a range of site qualities. The range for some habitat types is very broad and for others quite narrow. The ones most critical in designing timber sales or silvicultural projects are those habitat types with narrow ranges of site quality that are either very high or very low.

Stockability

The concept of limited stockability has been applied to habitat types near the environmental extremes for tree growth (Steele and others 1983). Even though the trees attain good size and reflect a fair site index, the stands are not capable of supporting full or normal stocking.

NONTIMBER RESOURCES

Management objectives often favor forage, browse or other nontree vegetation. Knowledge of habitat types is essential to predict the response of the desired vegetation. In support of that view, the most confusing conference I ever attended concerned the effects of fire on ponderosa pine. One speaker had burned and obtained delightful stands of grass, another all the shrubs and browse anyone could ever want, another got lots of little pine trees, yet another was keeping little white fir trees out of the type. The only generalization possible was that if one did not know the habitat type, one could not know the effects of fire on ponderosa pine stands or the attribute of the understories one might be trying to enhance.

Forage Production

The quantity and quality of livestock forage in both early and late successional stages are generally predictable for a given habitat type. The estimates are not precise but are helpful in narrowing choices for treatment prescriptions.

Large-scale clearing of woodland types was done in the southwestern United States to improve forage for livestock and it produced mixed results. This was done largely prior to the development of habitat types for the area. Now that retreatment of some of these areas is being considered, habitat types will be useful in assessing potential response (Moir 1986).

Browse Production

Browse production in forest stands is affected by successional status within a habitat type and the nature of the treatment applied as well as the habitat type itself. On a habitat type such as grand fir/pachistima (Abies grandis/Pachistima myrsinites), burning will produce a shrub community comprised of palatable species, while mechanical clearing will produce a herbaceous and low shrub community with little browse (Daubenmire and Daubenmire 1968). On a ponderosa pine/Arizona fescue (Pinus ponderosa/Festuca arizonica) habitat type, neither treatment will produce a significant amount of browse (USDA Forest Service 1986).

Although the number of relationships may be very large, it is clear that getting the most out of prescriptions for browse production requires knowledge of habitat types.

LIMITATIONS

Habitat types are a powerful tool in silviculture, but they are limited in several ways. Each reflects a range of conditions, consequently potential responses are not a predictable as we would like to think they are. They reflect some factors affecting tree stands but by no means all. Thus they are not a substitute for soil surveys and other classifications that convey additional information. The multiple pathways in plant succession are influenced by macroclimatic events and chance factors that confound the influence of local environments.

In spite of the limitations of the concept, it has profoundly influenced silvicultural practice where it has been used. It can be expected to do so in the future and to find use in additional areas of the United States and perhaps elsewhere in the world.

REFERENCES

Alexander, Robert R. 1985. Major habitat types, community types and plant communities in the Rocky Mountains. Gen. Tech. Rep. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 105 p.

Daubenmire, R.; Daubenmire, Jean B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington Agriculture Experiment Station. 104 p.

Hoffman, George R.; Alexander, Robert R. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: a habitat type classification. Res. Pap. RM-376. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 48 p.

Larson, Milo J. 1977. Regeneration of meadow-associated forest stands of north central Idaho. Moscow, ID: University of Idaho. 106 p. Dissertation.

Moir, W. H. 1986. [Personal communication]. October, 1986. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Stage, Albert R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Steele, Robert; Cooper, Stephen V.; Ondov, David M.; Roberts, David W.; Pfister, Robert D. 1983. Forest habitat types of eastern Idaho-western Wyoming. Gen. Tech. Rep. INT-144. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

USDA Forest Service. 1985. FSH 2409-26a - Cutting methods handbook. Albuquerque, NM: U.S. Departemnt of Agriculture, Forest Service, Southwestern Region. 103 p.

USDA Forest Service. 1986. Forest and woodland habitat types (plant associations) of southern New Mexico and central Arizona (north of Mogollon Rim). Albuquerque, NM: U.S. Department of Agriculture, Forest Serivice, Southwestern Region. 136 p.

Youngblood, Andrew P.; Mauk, Ronald L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

USE OF HABITAT TYPES IN SETTING REFORESTATION STOCKING STANDARDS IN NORTHERN IDAHO

Arthur C. Zack

ABSTRACT: A northern Idaho National Forest developed site-specific reforestation stocking standards based upon habitat type groups. The standards were developed by local silviculturists relying on a combination of literature reviews, local experience and testing, and growth model verification. There are three parts to each stocking standard: a minimum number of potential crop trees per acre, a minimum percent stocked plots, and a subjective test for distribution of stocked plots. The stocking standards are an integral part of a four-part reforestation monitoring system that includes the standards, instructions for applying the standards, a reforestation examination system, and a computerized data base that tracks reforestation results. The four-part monitoring system provides for consistent evaluation of reforestation results, future refinement of reforestation standards and treatments based upon results, and accountability to managers, the public, and Congress. Basing standards on habitat type links reforestation objectives to the productive capability of the land, provides a link to projected forest plan outputs, and provides a framework for experience of local foresters.

INTRODUCTION

With growing resource demands upon a fixed land base, reforestation has become one of the most critical jobs of the USDA Forest Service. Stocking standards are necessary to determine whether the reforestation job has been adequately performed. In the Inland Northwest, as demands upon the land have grown throughout this century, there has been an evolution of reforestation stocking standards.

The major 1910 fire in northern Idaho put the Forest Service into the reforestation business on a large scale. The success of reforestation efforts had to be evaluated. Seedling counts per unit of land area are undoubtedly one of the oldest methods of evaluating regeneration. However, tree counts fail to address the problem of distribution and become rather expensive as the number of trees rises. Recognizing this, Lowdermilk (1921), working in Forest Service Northern Region (Montana and northern Idaho), began to use stocking percent of milacre plots as a method of evaluating reforestation success. By 1926, the Regional Forester decided that, for all Forest Service Northern Region reforestation surveys, milacre stocking would be the criterion for evaluating reforestation success, with 40 percent stocking of milacre plots defined as success. Haig (1931) believed that using stocked plot percentages was satisfactory, but that the size of the plot should be the inverse of the number of seedlings per acre necessary for full yields at rotation age. This argument led to Forest Service use of stocked 4-milacre plots in the western white pine type.

Wellner (1940) discussed three methods of evaluating regeneration in use in northern Idaho: number of trees per acre, milacre stocking percent, and 4-milacre stocking percent. He evaluated the three methods, presented data that allowed converting from one method to the other, and made recommendations for desirable stocking levels. Wellner recommended that average minimum satisfactory stocking for the white pine type be set at 1,000 trees per acre, or 65 percent 4-milacre stocking.

In the following decade there were a number of important articles about reforestation surveys and standards (Lynch and Schumacher 1941; Long 1947; Staebler 1949; Allen and others 1951). This interest was probably an outgrowth of the post-Depression, post-war increase in intensity of timber management on public lands. The emphasis was still on the stocked quadrat method of survey (primarily because of its low cost), but tree size, species, seedling condition, and management objectives were also considered.

The next period of strong interest in regeneration standards and surveys was from the mid-1970's up through the mid-1980's (Stage 1974; MacLeod 1977; Stein 1978; Kaltenberg 1978; nine papers on regeneration surveys presented in a technical session at the Society of American Foresters 1983 convention; Ferguson and others 1986). Increased environmental awareness, the visible end of any large amount of harvestable old growth timber in the United States, the ever-intensifying demands upon the forest land base, and concern about a reforestation backlog on National Forest lands were probably all reasons for this renewed interest in reforestation. Awareness of the limitations of stocked plot surveys, combined with increased management

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Arthur C. Zack is Assistant Forest Silviculturist, Idaho Panhandle National Forests, Forest Service, U.S. Department of Agriculture, Coeur d'Alene, ID.

intensity, brought back into favor those reforestation examination systems that counted and recorded information about individual seedlings. There was renewed discussion of tying reforestation standards and surveys to land productivity and management objectives, and thus to detailed land classification systems rather than broad regional cover types.

In the mid-1970's, the Forest Service became concerned about the reforestation backlog that accumulated during the previous two decades of increasing timber harvests. Congress responded through the National Forest Management Act of 1976 (NFMA). Some of the pertinent NFMA language reads as follows:

> It is the policy of the Congress that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple use sustained yield management in accordance with land management plans. Accordingly, the Secretary is directed to identify and report to Congress annually . . . the amount and location by forests and States and by productivity class, where practicable, of all lands in the National Forest System where objectives of the land management plans indicate the need to reforest areas that have been cut-over or otherwise denuded or deforested . . . All national forest lands treated from year to year shall be examined after the first and third growing seasons and certified by the Secretary in the report provided under this section as to stocking rate, growth rate in relation to potential and other pertinent measures.
>
> . . . timber will be harvested from National Forest System lands only where . . . there is assurance that such lands can be adequately restocked within five years after harvest . . .

There was now a clearly stated Congressional mandate to maintain forest cover, to reforest the backlog within 10 years, and to spend significant amounts of money to meet these objectives. Appropriate forest cover was defined not just as a stocking rate, as might have been determined from stocked plot percentages. It also included species of trees and rate of growth, was linked to management objectives as defined in forest plans, and was tied to potential productivity. In addition, the Forest Service was directed to examine treated lands at particular times, to report to Congress quite specifically about the status of regeneration, to certify the acceptability of its regeneration according to defined standards, and to refrain from harvesting any land that was not generally capable of being satisfactorily regenerated within 5 years of final harvest.

In late 1984, the Idaho Panhandle National Forests began to develop reforestation stocking standards. Forest Service Northern Region stocking guidelines and regeneration examination formats had been in existence for years. However, both systems were fairly general, and there was great variation in how they were applied. There was also a regional timber stand data base that had the capability to track reforestation results, but its use for this purpose was scattered and inconsistent. Professional foresters felt the need for site specific, locally applied tools to evaluate reforestation results and learn from past practices. As public interest groups began to raise questions about reforestation results, better standards were needed for both data collection and reforestation evaluation. The Forest Plan, which was also getting close to completion, needed a tie between projected plan outputs and standards for reforestation.

OBJECTIVES

In December of 1984, the Idaho Panhandle National Forests began to develop standards for a reforestation monitoring system that would address the above needs. This reforestation monitoring system had to meet the following objectives:

1. Fulfill NFMA requirements by addressing degree of stocking, species composition, rate of growth, stand conditions, forest plan management objectives, and potential land productivity;
2. Be able to deal with both the density and distribution of stocking;
3. Be flexible enough to apply to the variety of local conditions found across the Forest;
4. Be expressed in terms that the average forestry field worker could reasonably understand, rapidly accept, and easily put into use;
5. Be capable of direct incorporation into a stand prescription;
6. Include a relatively inexpensive, quick, efficient, and reliable survey system to ensure compliance with stocking standards;
7. Be useful in a variety of circumstances for making decisions about the acceptability of regeneration;
8. Be reasonably compatible with existing systems, including the Forest Service Northern Region Stand Exam System and the Timber Stand Data Base; and
9. Be capable of displaying clear results to managers, the public, and Congress.

METHODS

The entire system of stocking standards was developed over a 3-year period. This allowed for taking one piece of the problem at a time, drafting standards, field testing, and making necessary revisions. To utilize local experience and gain local acceptance, the job was carried out by a working group of experienced silviculturists from Ranger Districts across the Forest, the Forest silviculturist and his assistant, and a research forester from the Forest Service, Intermountain Research Station in Moscow, ID.

Each year, the Silviculture staff in the Supervisor's Office of the Idaho Panhandle Nationa Forests wrote to the local Ranger Districts, defining the part of the problem to be considered, nominating silviculturists to help in the effort, and asking for literature pertinent to the topic. Based on literature reviews, local field experience, experience with the Regeneration Establishment Model (Ferguson and others 1986), and a healthy dose of professional judgment, the group developed a draft standard. The draft standard was reviewed by the forest planning staff, and modified as necessary. Prognosis Model (Stage 1973; Wykoff and others 1982) projections were made to test assumptions in the draft standards. Following review by the entire forest silviculture group, the standard was put into trial practice on all Ranger Districts for one field season.

The next winter, another silviculture working group was assembled. Each year, about half the group would be people from the previous year, and half would be new people. This maintained continuity while gaining diverse skills and perspectives. This was also useful in fostering a broad sense of ownership of the results. The group reviewed the field results and modified the draft standards from the previous year. Then, using the same methodology, the group considered the next piece of the problem. The Idaho Panhandle National Forests' reforestation stocking standards are now available and will be written into the Forest Service Northern Region Reforestation Handbook as a local forest supplement.

REFORESTATION MONITORING SYSTEM

The reforestation stocking standards are the first part of a four-part reforestation monitoring system. The basic format of the system ties the reforestation stocking standards to the productive capability of the individual forest stand. It was decided that the habitat types of northern Idaho (Cooper and others 1987) would be the measure of land capability. Habitat types were utilized for four reasons. Locally, they were the most widely used and easily applied measure of land capability. They provided a link to potential for timber productivity (Cooper and others 1987). They provided a tie to timber outputs in the Forest Plan (USDA 1987). And they provided a framework for local observations about reforestation results and problems.

The reforestation monitoring system consists of four parts:

1. Reforestation stocking standards by habitat type group, with each habitat type group standard specifying a minimum acceptable number of potential crop trees and a minimum percent stocked plots;

2. Instructions for applying the stocking standards;

3. Standards for a regeneration establishment examination to determine if the stocking standard has been met; and

4. Instructions on how the stocking standards, activities to meet those standards, and regeneration examination results will be recorded in the Forest Service Northern Region computerized Timber Stand Data Base.

Reforestation Stocking Standards

Minimum stocking standards for the Idaho Panhandle National Forests are shown in table 1. Habitat type groups--defined as good, medium, and poor sites--are used to index site productivity. Regeneration areas not meeting these standards are candidates for remedial treatments.

Potential crop trees are limited on a plot basis to the equivalent of 900 trees per acre. These trees must be at least 3 feet apart, of good form and vigor, of acceptable species (based on the silvicultural prescription), free to grow, and have no damaging agents that would preclude trees from reaching rotation age without serious volume loss. In addition, natural regeneration must have survived a minimum of two full growing seasons before being counted as potential crop trees. Potential crop trees will be the best trees on the plot that meet these conditions.

Table 1--Minimum stocking standards for the Idaho Panhandle National Forests

Site/habitat type	Potential crop trees per acre	Percent stocked plots* 1/300 A.	Percent stocked plots* 1/100 A.
Good sites: all cedar and western hemlock series	400	65	80
Medium sites: all grand fir series, best subalpine fir and mtn. hemlock series; ABLA/CACA STAM, CLUN; TSME/CLUN	300	60	80
Poor sites: all others not in above groups; all Douglas-fir series; ABLA/MEFE, VACA, XETE, LUHI, VASC; TSME/MEFE, XETE, LUHI	200	50	70

*A stocked plot is defined as a plot where the tree count of potential crop trees is equal to at least 2/3 the stocking objective for that site. (Example: 1/100 acre plot where 400 trees/acre are required; if there are three trees on the plot, that is 3/4 of stocking objective and the plot is counted as a stocked plot; if there are two trees on the plot, that is only 1/2 of the stocking objective and the plot is not counted as being stocked).

Instructions for Applying Stocking Standards

The Forest Service classifies regenerating stands as certified, progressing, or failed. A certified stand is adequately stocked with well-spaced, established, suitable, free-to-grow trees, and can be removed from regeneration status. Progressing stands are regenerating at an acceptable rate and are not expected to need any significant further treatment to become adequately stocked. Failed stands will not be adequately stocked within an acceptable time without further treatment.

Certification as adequately stocked is based upon satisfying all parts of a three-part standard. Habitat type is used to properly enter the stocking standards table. For certification, a stand must:

1. Have the minimum number of potential crop trees per acre;
2. Have the minimum percent stocked plots; and
3. Be uniformly stocked based upon a subjective analysis of the distribution of stocked plots. Even when the first two conditions are met, if nonstocked plots are clumped, it is likely that the stand is not satisfactorily stocked, and additional treatment may be necessary.

These are minimum standards only, and are not meant to usurp the responsibility of Forest Service silviculturists to set stocking objectives through individual stand prescriptions. These standards are meant to be applied to sites where timber management is a major objective. The stand prescription may call for different stocking levels as a result of other management objectives or local site conditions. If site conditions or management objectives necessitate a prescription with other stocking objectives, those other objectives and their rationale are documented in the stand prescription included in the stand records. If the stand is certified at less than the minimum standards, the reason for that decision is also documented.

Standards for Regeneration Examination

The examination is used to determine the stocking condition of a regeneration unit. Satisfactory stocking is based upon the stand prescription or the minimum standards shown in table 1.

The examination is an abbreviated version of the standard Forest Service Northern Region stand examination. Plots are located on a randomly placed grid that evenly samples the entire stand. Sample design is such that the 95 percent confidence interval about the mean number of potential crop trees shall be no more than ±20 percent of the mean, and there shall be at least one plot for every 2 acres. Under common stand conditions, 20 to 30 plots will meet these design objectives.

The examination record includes a topographic map of the stand showing all plot locations, with each plot labeled as either stocked, nonstocked but capable of stocking, or nonstockable. Stocked plots and potential crop trees are as defined in table 1. A plot is defined as nonstockable when over 50 percent of its area is not capable of supporting normally growing conifers.

The examination is based on either 1/100- or 1/300-acre circular plots. All recorded heights and growth rates are estimated. A tally is made of potential crop trees on the plot up to a maximum number equivalent to 900 trees per acre. Potential crop trees are grouped by species and 1-foot height classes, and average height is recorded for each group. Height growth for the last complete year to the nearest 1/10-foot is recorded for each group. A rough estimate is made of the number of trees in excess of full stocking. They are grouped in very broad height classes, and each group is recorded by the species that makes up a plurality of that group. An average height is assigned to each group. If there are serious damaging agents, or potentially competitive vegetation, they are recorded. The inventory normally takes 1 to 5 minutes per plot.

If there is already existing habitat type information for the stand, habitat types are not recorded in the regeneration examination. Any record of habitat type based on examination prior to harvest is likely to be more accurate than a habitat type determination after disturbance.

Data Base Standards

Stand habitat type, site characteristics, prescription stocking objectives in trees per acre, activities on the ground, and regeneration examination results are recorded in the Forest Service Northern Region computerized Timber Stand Data Base. For each regeneration exam, we record potential crop trees per acre and the status of the regeneration (certified, progressing, or failed). Following tree planting, first- and third-year examinations are mandatory. Examinations are repeated until the stand is either certified as adequately stocked according to the minimum standards, or a decision is made and documented to accept a lower level of stocking.

Applications

This system was partially implemented as it was being developed over the last 3 years, and was fully implemented in the fall of 1987. Positive results are already apparent. With clear, site-specific stocking standards, there is a consistent basis for making decisions on whether regenerated stands are adequately stocked or need further treatment. Stocked stands have now been certified as adequately stocked, and are no longer being scheduled for unnecessary examinations. Nonstocked stands that were undetected in previous inventory and tracking systems have now been identified and scheduled for appropriate treatment. Since silviculturists now have a site-specific standard for evaluating success, they also have a basis for learning from the results of their reforestation efforts. A detailed picture of the reforestation situation on the Idaho Panhandle National Forests is now available for land managers and the public. Reports to Congress on reforestation status now include better, and more complete, information.

DISCUSSION

Strengths of the System

The new three-part stocking standards overcome limitiations of earlier systems that relied either totally on stocked plot percentages (without any tree information), or relied totally on expensive and time-consuming complete tree inventories. Tallying potential crop trees provides seedling information that helps evaluate regeneration progress. Limiting the number of potential crop trees per plot avoids generating meaningless averages from overstocked plots, and also limits seedling counts to potentially merchantable trees at rotation age. The limitation on potential crop trees tallied also holds down examination time and expense. Including a minimum acceptable percentage stocked plots provides a simple and statistically sound method of evaluating tree distribution. The subjective evaluation of stocked plot distribution overcomes the inability of simple stocked plot percentages to identify clumpy stocking or nonstocked holes in a stand.

Creating the stocking standards within a four-part monitoring system means there is consistency in standards and in how the standards are applied. The whole system provides a measurable, trackable tool for evaluating reforestation success. The system is a useful management tool for silviculturists, provides a public land management agency with accountability to the public and Congress, and can be used to document compliance with the legal requirements of the National Forest Management Act.

The use of a computerized data base for storing both stand and site information plus reforestation results provides a source of data that can be used to refine the stocking standards. This data base also provides a tool for refining reforestation techniques. Data base reports have been developed to sort reforestation results by habitat type, slope, aspect, elevation, or year of planting. Later in the rotation, stand condition, growth, and yield can be compared to initial reforestation results.

Although the stocking standards are created for broad groups of habitat types, stand information is stored in the data base by individual habitat type. This provides the ability to rearrange or split out different habitat type groups as future results dictate.

Tying the standards to habitat types provides some special strengths. Habitat types are a comprehensive measure of the land's vegetative capability; they are currently in common use by northern Idaho forest land managers (Pfister 1980). Habitat type information is available for almost all forest stands that have been inventoried by the Forest Service in this area. Habitat types provide a tie to projected timber outputs because Forest Plan yield tables were built around the same habitat type groups. Silviculturists use habitat types to categorize many of their observations about forest responses. Since the standards were built in large part by local experience, and since habitat types frequently serve as the framework for acquiring new local experience, there is the capability to modify the habitat type specific standards as newly acquired local experience may dictate.

Limitations and Research Needs

The stocking standards have a number of limitations because they are structured by habitat type. Every one of these limitations also points to an avenue that needs further research.

Habitat type classifications are based on potential climax vegetation (Cooper and others 1987). Since the classification scheme does not start from productivity classes, it cannot be assumed that habitat type alone will be a good predictor of productivity. In fact, although both Steele and others (1981) and Pfister and others (1977) show mean productivity levels by habitat type, there are very wide confidence intervals about those means. Cooper and others (1987) limit their productivity information to a table of mean basal areas and site indices by habitat type. Building yield tables by habitat type groups, and then tying reforestation stocking standards to those yields, may be questionable if habitat type is not a good predictor of potential yield.

There may be several successional pathways for a given habitat type (Arno and others 1985). Successional pathways may vary due to plant community composition at the time of disturbance, the type or intensity of disturbance, factor compensation, or chance factors like seed crops and weather. The successional community is the environment for reforestation; the habitat type may simply define the range of the possible successional communities and their end point. A variety of successional communities may indicate a variety of conditions for regeneration. It is by no means obvious that a single reforestation treatment or stocking standard will suffice to meet management objectives for all the successional communities possible within a habitat type. Because reforestation takes place in early seral communities, there is a need for research on successional pathways of northern Idaho habitat types.

The biggest weakness in using habitat types to develop stocking standards comes from factor compensation. Habitat types are essentially bioindicators of the long-term, total environment. However, different combinations of environmental factors may combine to produce essentially the same climax plant community (Cooper and others 1987). For example, a given habitat type may occur on south slopes where soils are deep and have a high moisture holding capacity. With more droughty soils, the same habitat type may be limited to north slopes or the bottom of drainages. Although the climax plant community may ultimately be the same, it is likely that these two situations might have very different patterns of early stand development. It may be that the further a community is from climax, the more significant factor compensation is in indicating different environmental conditions for plant growth. There is a need to explore the implications of factor compensation in relation to the use of habitat types as a management tool for early seral stands. It may be that for early seral communities, topographic or edaphic features are a necessary companion of habitat types in defining management alternatives.

CONCLUSIONS

Reforestation stocking standards were developed with separate stocking levels for three habitat type groups in northern Idaho. The standards are based on a combination of literature reviews, local experience and testing, and growth model verification. There are three parts to each stocking standard: a minimum number of potential crop trees per acre, a minimum percent stocked plots, and a subjective test for evaluating distribution of stocked plots.

The stocking standards are an integral part of a four-part reforestation monitoring system. The system includes the stocking standards, instructions for applying the stocking standards, a reforestation examination system to measure compliance with the stocking standards, and a computerized data base for storing and tracking reforestation results over the long term.

The stocking standards are a useful tool to land managers, provide accountability to the public and Congress, provide a link to projected forest plan outputs, and meet the legal requirements of the National Forest Management Act. The structure of the entire reforestation monitoring system provides a framework to further refine both reforestation practices and the stocking standards themselves, based on results of their application.

REFERENCES

Allen, George S.; Griffith, B. G.; Ker, John W. 1951. A comparison of several regeneration survey methods in terms of cost and usefulness. Research Note 3. Vancouver, BC, Canada: University of British Columbia Faculty of Forestry. 6 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Cooper, Stephen V.; Neiman, Kenneth E.; Steele, Robert; Roberts, David W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Ferguson, Dennis E.; Stage, Albert R.; Boyd, Raymond J. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. Forest Science Monograph 26. Bethesda, MD: Society of American Foresters. 41 p.

Haig, I. T. 1931. The stocked-quadrat method of sampling reproduction stands. Journal of Forestry. 29:747-749.

Kaltenberg, Michael C. 1978. Evaluation of regeneration sampling methods: a Monte Carlo analysis using simulated stands. Res. Rep. No. 39. Olympia, WA: State of Washington, Department of Natural Resources. 50 p.

Long, H. D. 1947. Problems of regeneration surveys. Woodland Research No. 20 F-2. Montreal, PQ: Pulp and Paper Research Institute of Canada. 3 p.

Lowdermilk, W. C. 1921. A unit of area as a unit of restocking. Applied Forestry Notes No. 17. Missoula, MT: U.S. Department of Agriculture, Forest Service, Region 1. 3 p.

Lynch, D. W.; Schumacher, F. X. 1941. Concerning the dispersion of natural regeneration. Journal of Forestry. 39:49-51.

Macleod, D. 1977. Accuracy of regeneration stocking estimates: tests with simulated data. Forest Chronicles. 53:77-81.

National Forest Management Act of 1976. 90 Stat. 2949; U.S.C. 1600 note.

Pfister, Robert D. 1980. The use of habitat types in making silvicultural decisions. In: The scientific and technical basis for land classification; a joint technical session; 1980 October 7; Spokane, WA. Bethesda, MD: Society of American Foresters: 34-38.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Society of American Foresters. 1983. Regeneration surveys: proceedings of the 1983 technical session of the inventory, remote sensing and photogrammetry, and biometrics working groups. In: New forests for a changing world; proceedings of the 1983 convention of the Society of American Foresters, 1983 October 17; Portland, OR. Bethesda, MD: Society of American Foresters. 48 p.

Staebler, George R. 1949. Predicting the volume and normality of reproduction stands of Douglas-fir. Journal of Forestry. 47:828-833.

Stage, Albert R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Stage, Albert R. 1974. Picturing the future forest from regeneration surveys--a research program and scale for defining adequate stocking. In: Permanent association committees proceedings; 65th Western Foresty Conference; 1974 December 3; Spokane, WA: 74-76.

Stein, William I. 1978. Reforestation evaluation. In: Cleary, Brian D.; Graves, Robert D.; Hermann, Richard K., eds. Regenerating Oregon's forests. Corvallis, OR: Oregon State University School of Forestry: 205-221.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

USDA. 1987. Forest Plan, Idaho Panhandle National Forests. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Wellner, C. A. 1940. Relationships between three measures of stocking in natural reproduction of the western white pine type. Journal of Forestry. 38:636-638.

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

ELK HABITAT MANAGEMENT IN THE NORTHWESTERN UNITED STATES

Peter Zager

ABSTRACT: Elk habitat management guidelines are based on habitat potential, habitat effectiveness, and biologists' judgments. Habitat potential addresses the relative availability of security and thermal cover, and forage; it is based on vegetative cover types and structure. Habitat effectiveness evaluates habitat loss due to roads in elk habitat; it is based on road density and cover types.

INTRODUCTION

In the public's eye, the number of animals in a population or specific area is the central issue in most wildlife resource debates. Because the public interest dictates policy and wildlife management depends on public support, population and harvest parameters will continue to be a primary focus of wildlife research and management. That may be acceptable if biologists understand that harvest levels and population status are relative to the quantity and quality of available habitat.

Fortunately, it is clear to most wildlife professionals that wildlife management is simply a byproduct of habitat interrelationships. Habitat has received considerable management and research attention, and it is clear that simply defining the primary habitat requirements of a species--food, water, shelter, and space--is not enough to drive management programs. But identifying and evaluating the factors that influence these requirements is no easy task, partly because many of the species of interest are very adaptable--they use a variety of habitats in various ways. Elk (Cervus elaphus) in the northwestern United States are a good example.

Historically, elk ranged from the Atlantic Coast, across the Great Plains, through the Rocky Mountains, and to the California coast, and from Mexico to British Columbia and Alberta (Bryant and Maser 1982). Elk occurred in a variety of habitats that formed a gradient from open habitats with little cover to habitat dominated by forest with few openings. Habitat productivity, weather, topography, and so forth varied considerably from one region to the next, yet all these areas provided elk with their basic requirements of food, water, and shelter.

Today, elk and their habitat are much more restricted. There is a relatively large core of Rocky Mountain elk and elk habitat, and smaller populations of transplanted Rocky Mountain elk, pockets of Manitoban elk and Tule elk. Roosevelt elk are fairly widespread in western Oregon and Washington, and northern California (Bryant and Maser 1982).

Elk are the premier big game species in Idaho and probably in the western United States. Hunters in Idaho spend approximately 500,000 hunter days, with an estimated value of nearly $20 million, in pursuit of elk each year. There is also an unmeasured but substantial demand for the opportunity to view and photograph elk. Because of the species' importance, research has focused on elk and their habitat for years. This work has shown that even though elk are widespread geographically, they exhibit definite habitat use patterns that necessarily reflect habitat availability. Such habitat use patterns may be unique to geographic areas. For example, Arizona elk occupying the ponderosa pine (Pinus ponderosa) zone have different habitats available to them than northern Idaho elk in the cedar (Thuja plicata)/hemlock (Tsuga heterophylla) zone or coastal elk in the Sitka spruce (Picea sitchensis) zone. But typically, elk habitat use is correlated with plant phenology--they key on succulent forage and new growth for most of the year, and use available cover during the hunting season, and on hot or windy days.

Because of the inherent adaptability of the species and resultant variability in habitat use, it is difficult to develop useful generalizations about elk habitat use. Yet generalizations allow one to develop models that have widespread application--the search for such generalizations is basic to wildlife research. As research evolved and knowledge accumulated, an approach to elk habitat management began to crystalize, leading to a conceptual model of elk habitat that has two facets, Habitat Potential and Habitat Effectiveness. These are the basis for the elk habitat management guidelines developed for different regions throughout the western United States. (e.g., Thomas and others 1979; Leege 1984; Lyon and others 1985).

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Peter Zager is Senior Wildlife Research Biologist, Idaho Department of Fish and Game, Coeur d'Alene, ID.

HABITAT POTENTIAL

Habitat potential represents elk habitat as perceived by biologists. This perceived elk habitat provides for all the biological needs of elk. Habitat potential does not address the number of animals an area can support; it would be difficult to convert habitat variables to elk numbers because hunting regulations and seasons are the primary population regulator for most elk populations. Habitat potential reflects current environmental conditions and, therefore, is not equivalent to site potential, or habitat type.

The basis of habitat potential is a cover:forage ratio as determined across a large area. This ratio is based on the percentage of an area that qualifies as cover versus that qualifying as forage. The typical habitat potential guideline, derived from work in the Blue Mountains of Washington and Oregon (Black and others 1976; Thomas and others 1979), is a 40:60 cover:forage ratio, that is, 40 percent of the area provides cover and 60 percent of the area is classified as forage areas.

Cover

Cover, or crown cover, is coniferous or deciduous vegetation used by wildlife for security or to ameliorate environmental conditions. Vegetative structure and canopy cover are used to define cover; species composition may be a secondary consideration. Some biologists include all areas with at least 60 percent cover in this category (Wisdom and others 1986).

Biologists further differentiate between hiding or security cover and thermal cover. Black and others (1976) and Thomas and others (1979) reported that 50 percent of the cover should be hiding cover, 25 percent should be thermal cover, and the remaining 25 percent either thermal or security cover, whichever is limiting. Security cover is used by elk to escape from danger; it includes vegetation that hides 90 percent of a standing adult elk at ≦200 feet (Thomas and others 1979). The importance of security cover to hunted elk populations is unarguable. Without adequate security cover, elk are quite vulnerable to hunters and hunting seasons must be restrictive. The characteristics of good security cover are open for discussion, however. It is difficult to evaluate security cover because elk are generally able to move from one secure area to another when disturbed. Furthermore, the types of stands that provide security cover necessarily vary as vegetation composition and structure vary, with size of the area, and with topography. In some areas, topography can provide important security cover independent of or in conjunction with vegetative cover and structure. Canfield and others (1986) showed how topography can work against vegetative cover and structure by altering the viewing angle.

Thermal cover ameliorates the effects of weather, reduces travel costs, and provides food sources not available in open areas, such as lichens and low-growing plants that may be snowcovered during the winter. A coniferous stand >40 feet tall with an average canopy closure of >70 percent is classified as thermal cover for elk (Thomas and others 1979). Multi-storied stands are considered superior because they are typically composed of several different species of different ages and therefore not as vulnerable to catastrophic loss. The importance of thermal cover has been questioned by some biologists. Elk are capable of tolerating temperature extremes, as evidenced by historic and current distribution that includes areas with winter temperatures that are tens of degrees below freezing to hot dry sagebrush or plains habitats (Bryant and Maser 1982). Peek and others (1982) argue that though thermal cover may not be a requisite for survival, it may influence herd productivity and vigor by moderating temperatures and thus reducing physiological stress levels.

Forage

Areas that do not provide cover, such as meadows and open sapling-pole stands, are classified as forage areas. These areas generally have an overstory canopy closure of <70 percent and an average tree height of ≦40 feet.

Natural and artificial open areas in heavily forested areas often produce more forage than forest stands on similar sites and may be used extensively by elk if security cover is nearby. Logged sites typically produce substantially more forage than adjacent unlogged areas. Depending on the site productivity, this increase in forage production may last for 100 years in the northern Rocky Mountains (Lyon 1966), but 30 to 50 years is probably more typical in northern Idaho (Pengelly 1972). But the relationship between logging and elk populations is much more complex than a simple forage production model. Hanley and others (1987) have shown that the productivity and quality of vegetation in openings may vary considerably. Plants in certain logged areas may not be as palatable or nutritious as those occurring in forested areas. Hence, the actual nutritional value of logged areas may be something less than biomass measurements indicate. Such a relationship may have important implications for wildlife in that low quality forage areas may translate into a relatively unproductive elk population with low calf:cow ratios, low growth rates, and low overwinter survival, whereas high quality habitats may result in more productive, vigorous herds--with obvious management implications. Some recent habitat effectiveness models consider this (for example, Wisdom and others 1986), and I suspect future models will follow.

The juxtaposition, size, and arrangement of cover and forage are also important in evaluating elk habitat. The location of openings in relation to cover and roads is critical in determining elk use of an area. Lyon and Jensen (1980) found that elk use of openings was depressed when cover was inadequate or open roads were nearby. Therefore, distance to cover is often an important facet of elk habitat evaluation. Recommendations for this distance vary, but elk generally will use that portion of openings within 600 feet of the forest or cover edge. Such cover should be 600 to 2,000 feet wide for maximum use (Black and others 1976; Thomas and others 1979).

Obviously there is overlap between cover types--some stands that provide cover are also important forage-producing areas. To address this, Wisdom and others (1986) defined optimal cover as cover that provides security and thermal cover and forage areas.

These guidelines are just that--guidelines. They are designed to be modified by local biologists who are familiar with the unique characteristics of their area. It is not unusual to see different interpretations and applications of the guidelines in different areas, or even on adjacent Ranger Districts. To be truly useful, biologists must consider, at least subjectively, forage quality, adjacent cover, road density, slash accumulation, site treatment, and so forth. Such factors can have a profound effect on elk use of an area. Problems notwithstanding, Habitat Potential has created a framework within which managers can evaluate elk habitat in widely understood terms allowing them to compare and discuss management approaches.

HABITAT EFFECTIVENESS

Regardless of habitat potential, declines in elk use of habitat adjacent to roads have been documented throughout the species' range (Rost and Bailey 1974, 1979; Perry and Overly 1976; Hershey and Leege 1976; Marcum 1975, 1976; Burbridge and Neff 1976; Lyon 1979a, 1979b; Hayden-Wing 1979; Morgantini and Hudson 1979). The primary negative impact of high road density results from increased disturbance which displaces elk from preferred habitats. The width of the area avoided by elk ranges from 0.25 to 1.8 miles, depending on the amount and type of traffic, quality of the road, and density of cover adjacent to the road. In general, greater traffic flow on higher quality unpaved roads produces a larger area of avoidance (Hershey and Leege 1976; Perry and Overly 1976; Rost and Bailey 1979).

The avoidance of roads can be significant where road densities are high in that it can result in an effective loss of available habitat. The habitat management guidelines predict reductions in elk use ranging from 10 percent to 70 percent within 0.25 mile of an open road. Thomas and others (1979) reported habitat effectiveness for elk in Oregon can approach zero when road densities reach 6 miles per section. Lyon (1979a) calculated a road density of 3 miles per section would leave almost no effective habitat for elk in western Montana. It is readily apparent that road density and the associated disturbance are important factors in determining overall elk habitat suitability.

More importantly, new road construction allows increased hunter access, and may lead to increased hunter densities and higher elk harvest rates (Coggins 1976; Leege 1976; Thiessen 1976; Basile and Lonner 1979; Morgantini and Hudson 1979). Travel restrictions may mitigate the influence of roads on elk habitat use. Travel restrictions had a significant impact on elk distribution and hunter use in an area with open vegetation types, leading to a more even distribution of hunting pressure, elk sightings, and elk harvest, though the totals remained the same (Basile and Lonner 1979). Conversely, Lyon and others (1984) reported that travel restrictions did not alter elk distribution or the temporal distribution of hunters in an area with heavy cover.

ELK HABITAT MANAGEMENT GUIDELINES

Elk habitat management guidelines are based on a generalized model that incorporates a cover:forage function and a road density function. They are widely accepted and have been used throughout the western United States for several years. But the model has not been applied consistently because of "mechanical difficulties" and individual biologists' interpretations.

Mechanical difficulties arise because several different road models are available (Lyon 1979a, 1983; Perry and Overly 1976, 1977) and there are many ways to measure and calculate the cover:forage function (for example, PI types, habitat components, habitat types). Using different combinations of a road model and cover:forage calculation, a biologist can come to significantly different conclusions resulting in different management scenarios for a given piece of elk habitat.

To address this problem, Lyon (1984) conducted field validation tests to evaluate the road models and methods of calculating cover:forage ratios, and to determine the best combination for determining elk habitat suitability as indicated by actual elk use. He determined that, within the cover types tested, 50 percent of the variation in elk habitat use could be explained by an acceptable road density model. The best of the cover:forage functions improved predictions by 10 percent on only 50 percent of the validation sites.

This does not mean that cover:forage ratios are useless in terms of elk habitat management--they serve as a reasonable guideline and play a significant role in elk habitat management. It does mean, however, that we need to rethink some of our approaches to elk habitat research and management. We should be willing to take another look at elk habitat, and possibly bring in some fresh, innovative approaches before habitat potential can make a significant contribution to the models used to develop elk habitat management guidelines.

SOME POSSIBILITIES

Habitat Quality

One could look at animal condition or herd productivity as indirect measures of habitat quality. It seems that none of the currently used measures, such as blood and urine characteristics, can stand alone so it behooves us to use several simultaneously, allowing the independent measures to support each other. One could also evaluate habitat quality directly by measuring biomass and energy produced and truly available to elk in different habitats.

Coupled with knowledge of elk energy requirements (Robbins and others 1979; Parker and others 1979; Wickstrom and others 1984), this would permit a reasonable estimate of the potential carrying capacity of an area. Such information would provide a basis for the elk population targets that are so important in Forest Plans and similar documents.

Elk Mortality Rates

Determining factors that affect elk mortality rates would make a significant contribution to our understanding of elk habitat use. This includes studying road type and density, cover types, and hunter characteristics as they influence mortality rates. Elk can acclimate to roads and traffic if they are not harassed or killed (for example, Yellowstone National Park). But most elk populations are hunted, therefore acclimating to roads is generally not advantageous. Intuitively, it is apparent that different hunter groups use different types of roads in different ways, with different success rates, and different affects on elk populations. Describing such relationships would be an important aspect in determining the factors that influence mortality rate. Therefore, to determine elk mortality rates in a meaningful way, we must have good data on hunter density, distribution, attitude, and techniques given different road densities, road types, and cover types.

REFERENCES

Basile, J. V.; Lonner T. N. 1979. Vehicle restrictions influence elk and hunter distribution in Montana. Journal of Forestry. 77: 155-159.

Black, H.; Scherzinger, R. J.; Thomas, J. W. 1976. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. In: Hieb, Susan R., ed. Elk-loggingroads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 11-31.

Bryant, L. D.; Maser, C. 1982. Classification and distribution. In: Elk of North America. Harrisburg, PA: Stackpole Co. 1-59.

Burbridge, W. R.; Neff, D. J. 1976. Coconino National Forest--Arizona Game and Fish Department cooperative roads--wildlife study. In: Hieb, Susan R., ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 44-57.

Canfield, J. E.; Lyon, L. J.; Hillis, J. M. 1986. The influence of viewing angle on elk hiding cover in young timber stands. Res. Pap. INT-371. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 5 p.

Coggins, V. 1976. Controlled vehicle access during elk season in the Chesnimnus area, Oregon. In: Hieb, Susan R., ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 58-61.

Hanley, T. A.; Cates, R. G.; VanHorne, B.; McKendrick, J. D. 1987. Forest stand-age-related differences in apparent nutritional quality of forage for deer in southeastern Alaska. In: Provenza, F. D.; Flinders, J. T.; McArthur, E. D., compilers. Proceedings--symposium on plant-herbivore interactions. Gen. Tech. Rep. INT-222. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 9-17.

Hayden-Wing, L. D. 1979. Distribution of deer, elk, and moose on a winter range in south-eastern Idaho. In: Boyce, M. S.; Hayden-Wing, L. D., eds. North American elk: ecology, behavior, and management. Laramie, WY: University of Wyoming. 122-131.

Hershey, T. J.; Leege, T. A. 1976. Influences of logging on elk summer range in north-central Idaho. In: Hieb, Susan R.; ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 73-80.

Leege, T. A. 1976. Relationship of logging to decline of the Pete King elk herd. In: Hieb, Susan R., ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 6-10.

Leege, T. A. 1984. Guidelines for evaluating and managing summer elk habitat in northern Idaho. Wildlife Bulletin No. 11. Boise, ID. Idaho Department of Fish and Game. 37 p.

Lyon, L. J. 1966. Problems of habitat management for deer and elk in the northern forests. Res. Pap. INT-24. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 15 p.

Lyon, L. J. 1979a. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry. 77: 658-660.

Lyon, L. J. 1979b. Influences of logging and weather on elk distribution in western Montana. Res. Pap. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 11 p.

Lyon, L. J.; Jensen, C. 1980. Management implications of elk and deer use of clearcuts in Montana. Journal of Wildlife Management. 44: 352-362.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry. 81: 592-595.

Lyon, L. J. 1984. Field tests of elk/timber coordination guidelines. Res. Pap. INT-325. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Lyon, L. J.; Lonner T. N.; Weigand, J. P.; Marcum, C. L.; Edge, W. D.; Jones, J. D.; McCleerey, D. W.; Hicks, L. L. 1985. Coordinating elk and timber management. Final report of the Montana coop. elk-logging study, 1970-1985. 53 p.

Marcum, C. L. 1975. Summer-fall habitat selection and use by a western Montana elk herd. Missoula, MT: University of Montana. 188 p. Dissertation.

Marcum, C. L. 1976. Habitat selection and use during summer and fall months by a western Montana elk herd. In: Hieb, Susan R.; ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 91-96.

Morgantini, L. E.; Hudson, R. J. 1979. Human disturbance and habitat selection in elk. In: Boyce, M. S.; Hayden-Wing, L. D., eds. North American elk: ecology, behavior, and management. Laramie, WY: University of Wyoming. 132-139.

Parker, K. L.; Robbins, C. T.; Hanley, T. A. 1979. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48: 474-488.

Peek, J. M.; Scott, M. D.; Nelson, L. J.; Pierce, D. J.; Irwin, L. L. 1982. Role of cover in habitat management for big game in northwestern United States. Trans. North American Wildlife and Natural Resource Conference. 47: 363-373.

Pengelly, W. L. 1972. Clearcutting: detrimental aspects for wildlife resources. Journal of Soil and Water Conservation. 27: 255-258.

Perry, C.; Overly, R. 1976. Impacts of roads on big game distribution in portions of the Blue Mountains of Washington. In: Hieb, Susan R., ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 62-68.

Perry, C.; Overly, R. 1977. Impact of roads on big game distribution in portions of the Blue Mountains of Washington, 1972-1973. Applied Research Bulletin. No. 11. Olympia, WA: Washington Department of Game. 39 p.

Robbins, C. T.; Cohen, Y; Davitt, B. B. 1979. Energy expenditure by elk calves. Journal of Wildlife Management. 43: 445-453.

Rost, G. R.; Bailey, J. A. 1974. Responses of deer and elk to roads on the Roosevelt National Forest. Northwest Section, The Wildlife Society. Unpublished report.

Rost, G. R.; Bailey, J. A. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management. 43: 634-641.

Thiessen, J. L. 1976. Some relationships of elk to loggging, roading, and hunting in Idaho's game management Unit 39. In: Hieb, Susan R., ed. Elk-logging-roads symposium: Proceedings; 1975 December 16-17; Pullman, WA. Moscow, ID: University of Idaho: 3-5.

Thomas, J. W.; Black, H. Jr; Scherzinger, R. J.; Pederson, R. J. 1979. Deer and elk. In: Wildlife habitats in managed forests--the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture, Forest Service. 104-127.

Wickstrom, M. L.; Robbins, C. T.; Hanley, T. A.; Spalinger, D. E.; Parish, S. M. 1984. Food intake and foraging energetics of elk and mule deer. Journal of Wildlife Management. 48: 1285-1301.

Wisdom, M. J.; Bright, L. R.; Carey, C. G.; Hines, W. W.; Pederson, R. J.; Smithey, D. A.; Thomas, J. W.; Witmer, G. W. 1986. A model to evaluate elk habitat in western Oregon. Publication No. R6-F&WL-216-1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 36 p.

EVALUATION OF GRIZZLY BEAR HABITAT USING HABITAT TYPE AND COVER TYPE CLASSIFICATIONS

David J. Mattson and Richard R. Knight

ABSTRACT: We review the rationale for selecting habitat type and cover type as a framework for grizzly bear habitat analysis. Examples and interpretation of habitat type evaluations are presented.

INTRODUCTION

The Interagency Grizzly Bear Study Team (IGBST) was initiated in 1973 as a cooperative effort of the National Park Service, Forest Service, and since 1974 the States of Idaho, Montana, and Wyoming. The study team was charged with conducting research that would provide information for management of grizzly bears (Ursus arctos horribilis) inhabiting the Yellowstone area.

Habitat research has been a key part of the IGBST effort. Intensive data collection concerning grizzly bear habitat use was initiated in 1977 and continued through 1987. These data were collected principally in conjunction with radio-telemetry locations of instrumented bears and were derived from scats and detailed site description. Many data have been analyzed, and are employed in management of the Yellowstone grizzly bear; e.g., as input to the Yellowstone Cumulative Effects Analysis (Weaver and others 1986).

We stratified habitat data collection and analysis by habitat type (e.g., Steele and others 1983; Mueggler and Stewart 1980) and forest cover type (Despain 1986). In this paper we have reviewed our rationale for employing habitat types and cover types as we did, and give examples of analysis results and how the classifications served as an effective basis for grizzly bear habitat evaluation in our study area.

STUDY AREA

Our study area was approximately 2 million hectares in size, and consisted of high elevation central plateaus surrounded by extensive high relief mountain ranges. Elevations ranged from 1575 m to 3500 m, but were largely between 2100 m and 2750 m. The central plateaus were characterized by sterile and seasonally dry soils. The more fertile encircling mountains received varying amounts of precipitation depending on elevation, latitude, and longitude (Baker 1945). The climate was further characterized by long, cold winters and short, cool summers; average annual temperatures at study area weather stations ranged from 0 °C to 4.5 °C (NAOA climatological data).

Most of our study area lay in the subalpine zone. Smaller portions were in montane and alpine zones at lower and higher elevations, respectively (cf. Daubenmire 1978). Within the subalpine zone, lodgepole pine (Pinus contorta) stands encompassing sapling to near-climax conditions were predominant. Whitebark pine was especially common above 2545 m elevation. The ground layer was low and lacked diversity in most forest stands. Nonforest areas were typically dominated by graminoids and lower growing forbs; sagebrush (Artemisia spp.) species were also common.

Numerous mammal species occupied our study area. Large herds of bison (Bison bison) and elk (Cervus elaphus) occurred principally inside Yellowstone Park; smaller numbers of mule deer (Odocoileus hemionus), bighorn sheep (Ovis canadensis), moose (Alces alces), and pronghorn (Antelocapra americana) were also present. Small mammals were abundant and widespread.

CHOOSING A CLASSIFICATION SYSTEM

Several habitat classification systems were available for our use in data collection and analysis. Among these the most plausible choices were:

1. Develop a habitat classification specific to grizzly bears in the Yellowstone area.

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David J. Mattson is Wildlife Biologist and Richard R. Knight is Research Biologist, Interagency Grizzly Bear Study Team, National Park Service, Bozeman, MT.

2. Employ the existing habitat component classification developed for grizzly bears in northwestern Montana (cf. Zager and others 1980; Mace and Bissell 1986).

3. Employ existing habitat type and cover type classifications developed by plant ecologists for the Northern Rocky Mountains and Yellowstone area (cf. Mueggler and Stewart 1980; Steele and others 1983; Despain 1986).

The first two options were characterized by specialized classifications sensitive to parameters of grizzly bear habitat use. These types of habitat classification allowed more definitive segregation of high and low productivity or value site types, and were best suited to areas where habitat productivity was highly concentrated in distinct sites; for example, the base of particular types of avalanche chutes or early mid-successional moist-site shrub fields.

The first two options had several disadvantages. A land classification system specific to grizzly bears would have encumbered implementation of research information by management agencies. Our study as well as management agencies would not have been able to use existing ecological classification systems and associated maps and expertise for habitat evaluation and analysis. Our data also suggested a gradient of productivity not characterized by concentration in a few well-defined site types. In addition, Option 1 would have exacted the expense of sampling and analysis as well as the inconvenience of a posteriori development. Option 2 was disadvantaged by limited extrapolability; foods differed in distribution, availability, and importance to respective bear populations in northwest Montana and the Yellowstone area.

Option 3 was favored by several key factors. Ecologically versatile, field-tested habitat type classifications already existed. Technicians and consultants were available who were familiar with the systems and their use. Most importantly, managers were familiar with the Daubenmire habitat classification approach (cf. Daubenmire and Daubenmire 1968) and were involved in mapping large portions of the Yellowstone area accordingly; mapping has continued and should be completed for all occupied grizzly bear habitat within the Yellowstone area by 1988. Existence of these maps and acceptance of the classification system by managers favored our analysis and use of analysis results for evaluation of grizzly bear habitat and impacts of human activities.

Habitat types have potential shortcomings as a framework for analyzing and predicting wildlife habitat use. Because these types are general in nature, key parameters of habitat value may not be explicitly recognized; for example, density, species, and diameter-class of arboreal species or age and species composition of a shrub field. Another aspect of this criticism is that successional stage is not implicit in a habitat type designation; value of a given site to bears may be as much or more a function of successional stage as of habitat type. Further, much wildlife habitat use is keyed to microsites; a habitat type classification does not provide sufficient resolution to delineate these microsites.

We examined these potential shortcomings and concluded that all could be answered or were irrelevant given our study area and analysis objectives. Succession in the Yellowstone area appeared to be less complex than in more fertile and well-watered ecosystems such as in north Idaho or northwest Montana. The typically drier or infertile sites of Yellowstone engendered fewer potential successional pathways; typically the species occupying and dominating early successional communities were the same as those abundant in near-climax stands (Romme 1982; Despain 1983; Despain, pers. comm.). Thus, we deemed the forest cover type classification developed and described by Despain (1986) an adequate accounting of succession in forest habitat types of the Yellowstone area. Our analysis also indicated that proportionate representation of successional cover types was correlated with habitat type; near-climax stands predominated on wetter or higher elevation habitat types, while early to mid-successional stands predominated on more productive lower elevation types (fig. 1). This followed from

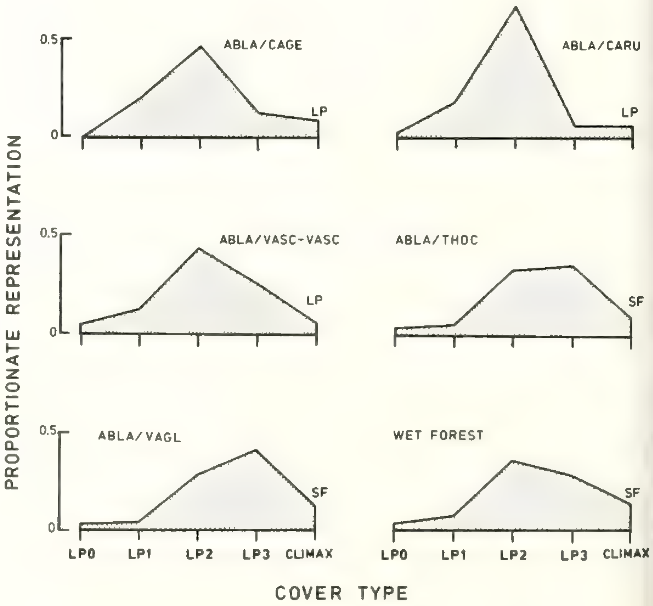

Figure 1--Proportionate cover type representation, by habitat type, for Yellowstone National Park.

the influence of elevation and site moisture on biomass and moisture content of fuels and consequently on time-specific probability of stand replacement fires within the time required for succession to near-climax conditions. This relationship between habitat type and successional stage was evident no doubt because very little of the timber in our study area was harvested or otherwise manipulated by humans. Thus, for a very large-scale analysis, habitat type also adequately accounted for successional stage.

We viewed our analysis in hierarchical terms. One of our objectives was to develop expedient and biologically meaningful methodology for evaluating grizzly bear habitat over a large area; this was significant because our study area encompassed approximately 2 million hectares. Within this expanse, we needed to differentiate productivity of areas as large of 200,000 hectares. At this scale, recognition of microsites was superfluous. While recognizing that grizzly bear use of habitat was keyed to specific parameters and microsites, we also observed that microsites were typically correlated with habitat types. We concluded that, on a large scale, habitat types would be an adequate framework for characterizing grizzly bear habitat use, while recognizing that all included activities did not occur on every hectare of a given habitat type and were more or less keyed to site variation within habitat types. At finer resolution analysis and evaluation of habitat we prioritized characterization and recognition of productive microsites.

For the remainder of this paper we will demonstrate how we used habitat type classifications and their derivatives as a framework for characterizing grizzly bear habitat use and evaluating habitat conditions in Yellowstone National Park. As part of this demonstration we analyzed habitat conditions during 1986, contrasted these conditions with those of 1979 and 1980, and interpreted habitat conditions in terms of consequences to the grizzly bear population.

EVALUATION OF HABITAT CONDITIONS

Habitat Type Evaluation

Yearly Averaged Productivity--We estimated habitat type productivity as a function of bear use, including observed feeding activity and information derived from scat analysis. Calculation of habitat productivity scores (HPS) for habitat types incorporated several factors: average feedsite density within a type, unit volume energetic value of extracted foods, and relative extracted volume per feedsite type. Feedsite density resulted from dividing number of recorded feedsites by proportionate habitat type area. This relative density estimate was weighted by mean value of feedsites recorded in the types, in turn a product of multiplying unit volume energetic value by relative volume extracted for different feeding activities. Habitat productivity scores were thus value-volume weighted density estimates of extracted food recorded within habitat types. This approach evolved from methodology described for calculating habitat productivity scores by Mattson and others (1986).

We calculated habitat productivity scores on a by-year, by-season basis, where we had sufficient data. Seasons were defined as April-May (APR-MAY), June-July (JUN-JUL), August (AUG), and September-October (SEP-OCT). These seasons reflected marked differences in food habits and habitat use patterns of grizzly bears in the Yellowstone area. With year- and season-specific HPS's available we were able to estimate year-to-year variation in productivity of types for each season. From this estimate we also calculated a coefficient of year-to-year variation ($S_x/\bar{X}$). An estimate of feeding activity diversity (e^H, where $H = -\Sigma$ pi ln (pi) (Shannon and Weaver 1963)) further characterized bear use of habitat types.

As an example, we estimated these variables for SEP-OCT, averaged for the years 1977, 1978, 1979, 1980, 1982, and 1986 (table 1). HPS varied 7X between low values of the Wet Meadow and Abla/Vasc-Vasc types to Abla-Pial's high value. This range of values was largely a function of whitebark pine (Pinus albicaulis) nut use and density of squirrel middens; grizzly bears used the high value pine nuts primarily by excavating squirrel caches of whitebark pine cones in middens (Kendall 1983). Given this range of average HPS's, fall productivity was most stable year-to-year in Wet Forest and Feid/Agca-Gevi types and least stable in Marsh/Fen, Wet Meadow, and Willow types. Year-to-year variation was not obviously related to diversity of feeding activity. Diversity was highest in the wetter forest types (Abla/Libo, Abla/Vagl, and Wet Forest) and mesic sagebrush types (Arca/Feid and Artr/Feid-Gevi). Implications of these numeric evaluations were clear:

1. Habitat types that received greatest average use and of potentially greatest importance to the bear population were identified.

2. Types with greatest year-to-year variation in productivity/use were identified; greater awareness of year-to-year variation in conditions was required if conflict between bears and humans and impacts on bear habitat were to be minimized in these types. Habitat types with higher year-to-year variation in productivity were also potentially important during some years; the Abla/Libo, Abla/Thoc, Arca/Feid, and Artr/Feid-Gevi types were known to be heavily used when whitebark pine nuts were unavailable.

Table 1--Mean diversity of feeding activity (e^H) and mean ($\bar{X}$), standard deviation ($S_{\bar{x}}$), coefficient of variation (C.V. = $S_{\bar{x}}/\bar{X}$), and maximum yearly value (MAX) for September-October habitat productivity scores, for the years 1977, 1978, 1979, 1980, 1982, and 1986, by habitat type or component

HABITAT TYPE (ACRONYM)	HABITAT PRODUCTIVITY SCORE				
	$\bar{X}$	$S_{\bar{x}}$	C.V.	MAX	e^H
Feid/Agca-Gevi	15.8	9.8	0.62	31.7	1.88
Wet Meadow	5.8	9.0	1.56	18.9	2.45
Marsh/Fen	14.6	33.7	2.45	82.5	2.00
Artr/Feid-Gevi	13.1	13.5	1.03	30.1	2.50
Arca/Feid	10.3	16.4	1.60	37.3	2.55
Willow	18.1	25.7	1.42	63.7	2.23
Psme(Abla)/Syal	7.3	10.6	1.45	27.2	2.23
Pico/Putr	7.4	5.1	0.70	14.0	1.38
Abla/Cage	7.7	7.4	0.97	19.9	1.70
Abla/Libo	14.0	16.2	1.16	35.2	2.43
Abla/Vagl	7.5	8.8	1.17	20.5	2.93
Wet Forest	10.9	5.4	0.50	17.8	2.60
Abla/Thoc	14.0	15.7	1.12	35.0	2.05
Abla/Vasc-Vasc	5.8	6.6	1.12	18.4	2.52
Abla/Vasc-Pial	27.2	26.9	0.99	66.3	1.66
Pial-Abla	42.6	34.3	0.80	73.5	1.62

3. Habitat types with several versus few kinds of feeding activity were identified; bear use of types with essentially one kind of feeding activity and one associated diet item would have been more vulnerable to detrimental management actions or climatic phenomena.

Seasonal Variation--Habitat productivity scores and feeding activity diversity of types varied substantially among seasons. As an example, seasonal scores and diversity were calculated for habitat types during 1986 (fig. 2). Examination of these patterns provided insight into how grizzly bears used their habitat and also provided a basis for management response to seasonal differences in bear use of habitat types. Although dissimilar in habitat characteristics, the Shaded Wetland and Abla-Pial types evidenced nearly identical trends in productivity and diversity; productivity was low in spring and fall, and peaked in early summer. Diversity of feeding activity peaked after peak in productivity. Both of these types were utilized by bears to obtain high value foods (spawning cutthroat trout (*Salmo clarkii*) in Shaded Wetland and whitebark pine nuts in Abla-Pial). Diversity of feeding activity tended to be lower while high-value foods were most available and increased as bears turned to secondary foods. Similar phenomena were evident in the Abla/Thoc habitat type. High diversity of feeding activity was associated with moderate to high productivity after late spring in wet habitat types (Wet Meadow and Wet Forest). Higher productivity in these types derived from high-density use of a diversity of low to moderate value foods. Seasonal patterns in mesic nonforest types were more complex; generally a decline in diversity accompanied peak use of yampa (*Perideridia gairdneri*) roots (during AUG in Artr/Feid-Gevi and during SEP-OCT in Feid-Agca-Gevi).

Successional Variation--Habitat types were characterized by substantial within-type variation in productivity. This variation was largely attributable to environmental clines within the types rather than to "random variation"; e.g., average fall productivity in the Abla/Vasc-Vasc type tended to be greater at higher elevations, and closer to boundaries with the Abla/Vasc-Pial or Abla-Pial types. A large part of within-type variation in productivity was attributable to secondary successional stage; i.e., progression of post-fire timber stands from herb-dominated to near-climax conditions.

Evaluation of productivity by successional stage had major management implications. The effects of different fire management plans and, less certainly, different timber management practices on grizzly bear habitat productivity were able to be evaluated. As an example, we calculated productivity by successional stage for SEP-OCT. We used a classification of successional stages described by Despain (1986); briefly, within the lodgepole pine (*Pinus contorta*) succession, LPO corresponded to the herb-to-sapling stage, LP1 to the pole stage, LP2 to the mature stage, and LP3 to the over-mature or decadent stage, where substantial basal area of subalpine fir (*Abies lasiocarpa*) and Engelman spruce (*Picea*

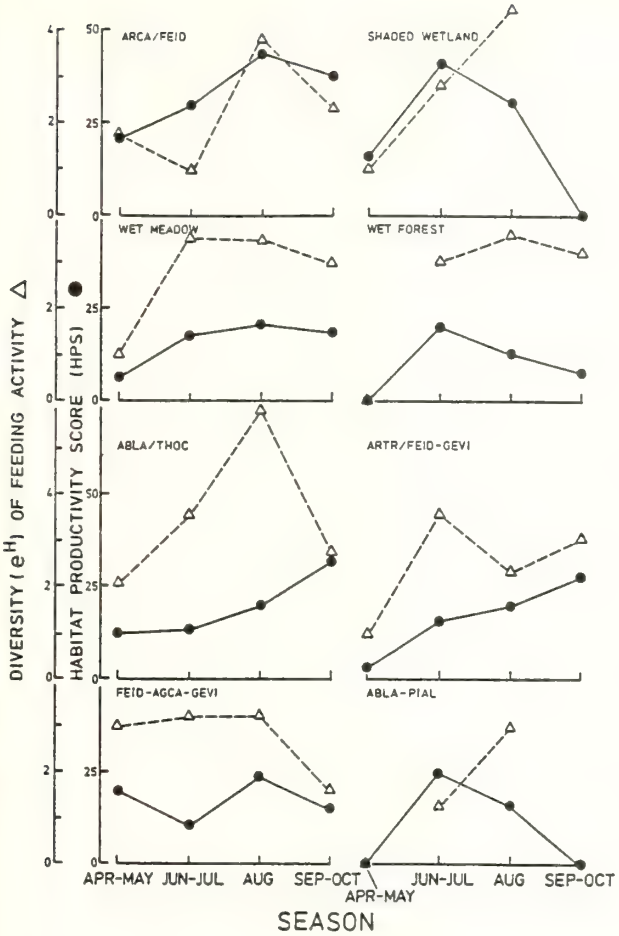

Figure 2--Seasonal habitat productivity scores (HPS) and diversity of feeding activity (e^H) for selected major habitat types in the Yellowstone area, for 1986.

engelmannii) was present. SF corresponded to near-climax spruce-fir and LP to climax lodgepole, where pole-to-mature lodgepole pine was replacing over-mature lodgepole pine in the stand.

Major trends in fall productivity scores of five major forest habitat types were evident (fig. 3). In all types productivity was lowest in the early successional LP0 and LP1 stages, and high in the near-climax SF and LP stages. Higher productivity characterized late successional LP3 stands in the Abla/Vasc-Vasc and Abla/Vasc-Pial types and mid-successional stands in the Abla/Thoc and Abla/Vasc-Pial types. Reversion of late-successional to early successional stages obviously decreased fall productivity of grizzly bear habitat in major forest habitat types of the Yellowstone area. This resulted from autecology and distribution of major diet items in the Yellowstone area; whitebark pine typically did not produce substantial cone crops until mature, and was long persistent even under near-climax conditions. Many other vegetal foods (e.g., Osmorhiza chilensis and Vaccinium globulare) were also apparently favored by semi-shaded

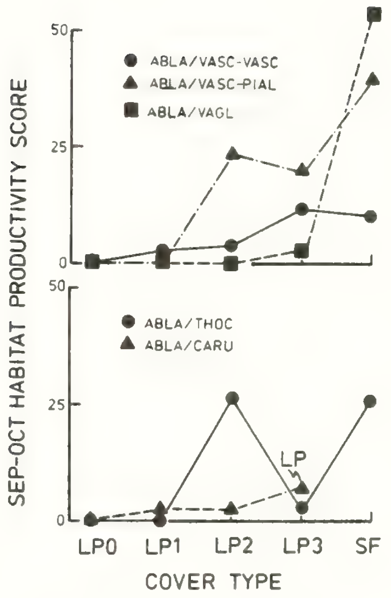

Figure 3--September-October (SEP-OCT) cover type habitat productivity scores (HPS), by selected major habitat types.

conditions typical of most mature forest stands in the Yellowstone area. Because the grazing resource was abundant, widely distributed, and apparently nonlimiting, any increase of grazing opportunity in burns or clearcuts did not offset losses of more critical resources.

Area Evaluation

Clinal Variation--Because habitat types are ecological classification units they were easily referenced to major environmental clines, in particular site moisture and elevation (as an approximation of ambient temperature). We plotted habitat types by these gradients to provide a base map against which to plot different variables (HPS, feeding activity diversity, and year-to-year variation in HPS). Mean elevation was obtained from Steele and others (1983). Site moisture was indexed by use of plant species scores. Codistribution of species among habitat types was first analyzed by cluster analysis (Hartigan 1983). Individual species were assigned a score based on observed habitat distribution with respect to site moisture (1 to 5, hydric to xeric); cluster analysis facilitated assignment of scores to species for which we had less confidence in our evaluation. Habitat type site moisture scores resulted from averaging scores of species present in the type with greater than 10% constancy.

Topological diagrams resulting from plot of HPS's along elevation and site moisture gradients provided additional insight into how productivity and bears were distributed in the Yellowstone area. As an example, we constructed topological diagrams of seasonal habitat productivity for 1986 as well as the SEP-OCT mean across all years (fig. 4). During APR-MAY

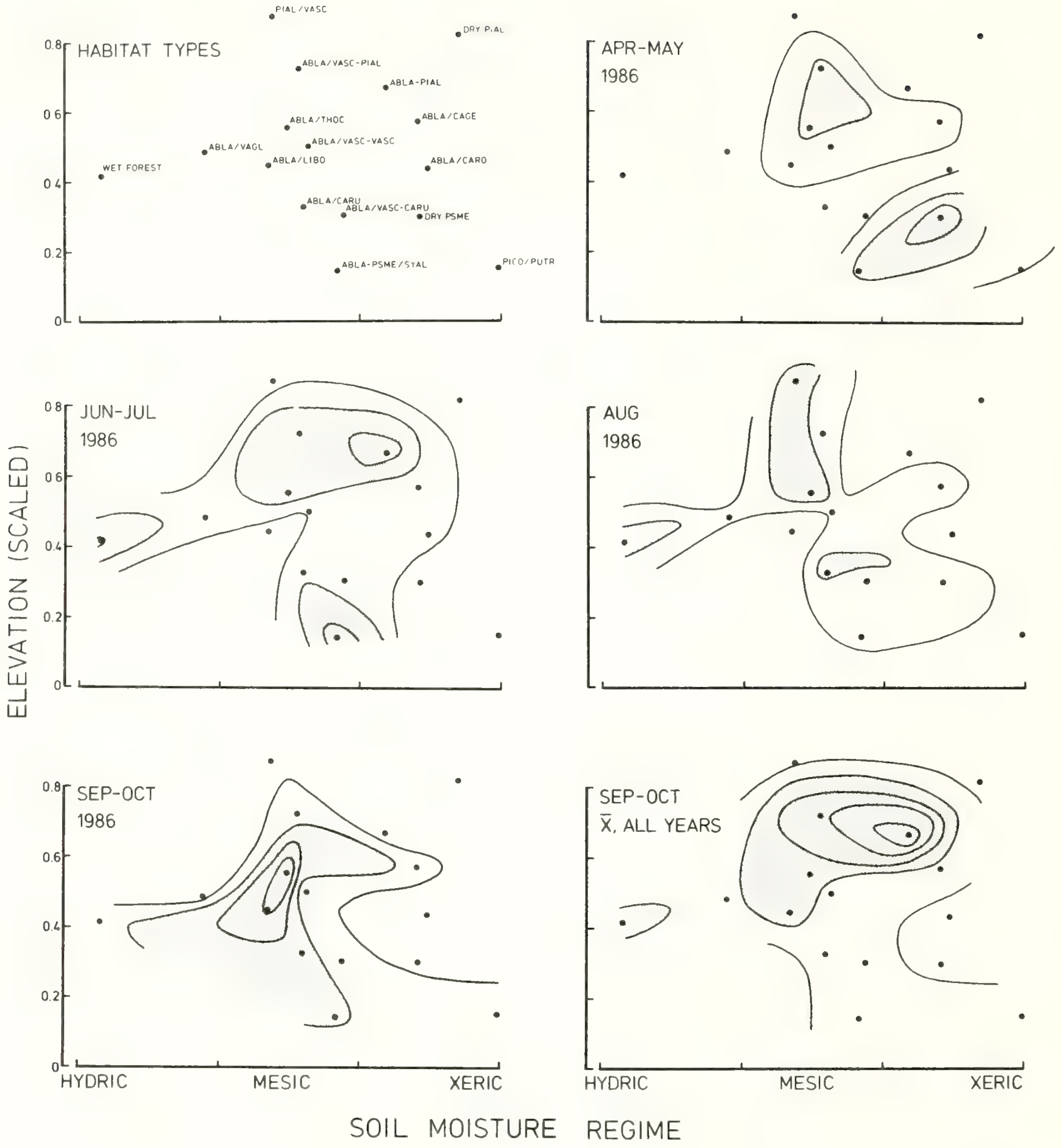

Figure 4--Topology of seasonal habitat productivity for 1986 and September-October (SEP-OCT) averaged across all years; relative to elevation and soil moisture regime.

greatest productivity occurred in association with use of ungulate carrion and squirrel caches of limber pine (Pinus flexilis) nuts on winter ranges at lower elevation drier sites. Secondarily, productivity focused on mesic and drier sites at higher elevations in association with early season use of over-wintered squirrel caches of whitebark pine nuts and use of ungulate carrion from more isolated higher elevation winter ranges.

During JUN-JUL three major peaks in productivity were evident--at high-elevation moist-to-dry sites associated with use of the over-wintered pine nut crop, at wet mid-elevation sites in association with use of grazed diet items and spawning trout, and at lower elevation mesic sites in association with continued use of carrion. During AUG, use of pine nuts shifted to moister sites, productivity continued high in wet sites but declined in lower elevation mesic sites.

In SEP-OCT of 1986 a major peak in productivity occurred on mesic mid- to low-elevation sites. This peak was associated with use of the grazing resource and sweet-cicely (Osmorhiza chilensis) roots. In contrast, average SEP-OCT productivity across all years strongly peaked at higher elevations and on drier sites, primarily in reflection of whitebark pine nut use. During fall of 1986 virtually no pine nuts were available, and bears reverted to secondary fall foods. Use of secondary foods brought bears to lower elevations and mesic sites that also coincided with most major human facilities in the Yellowstone area. Nutritional stress exacerbated this juxtaposition and fall of 1986 was characterized by a large number of management trappings and problems involving grizzly bears.

Area Variation--We estimated habitat productivity for large areas by a simple means: habitat productivity scores were weighted by proportionate area representation of corresponding habitat types to yield a weighted average. Area scores were calculated on a seasonal and yearly basis for Yellowstone National Park. We deemed our simple approach to estimating productivity sufficient given that we were making temporal comparisons of a given area that had many time-static parameters. Comparison of different geographic areas would have entailed a more complex model, as was used in the Cumulative Effects Model for the Yellowstone Ecosystem (Weaver and others 1986).

As an example of this calculation, we derived fall (SEP-OCT) habitat productivity scores for the years 1977, 1978, 1979, 1980, 1982, and 1986 (table 2). Area scores varied by 2.5X (C.V. = 0.32) from low scores in 1977 and 1986 to high scores in 1979 and 1980. These year- and season-specific productivity scores were apparently related to population phenomena of the Yellowstone area grizzly bear. Adult female mortality and total mortality for the period 1977 to 1982 were related to fall HPS (r = -0.85, P = 0.07; r = -0.86, P = 0.07, respectively); virtually all known mortality of subadult and adult bears in the Yellowstone area was by humans and occurred in fall or late summer. By implication, during years of lower habitat productivity, more bears came in conflict with humans and were killed. As previously mentioned, this was likely a consequence of nutritional stress and juxtaposition of human facilities and secondary fall habitat.

Table 2--Fall habitat productivity score (HPS), adult female and total mortality, and number of management trappings, by year

Year	Fall HPS	Adult female mortality	Total mortality	Management trappings
1977	5.6	4	17	5
1978	9.8	2	13	0
1979	12.2	2	13	0
1980	13.8	1	10	0
1982	9.5	4	17	7
1986	6.9	2	11	31

Between 1982 and 1986, managers increased efforts to preserve adult females. This was a consequence of analyses suggesting that death of one additional adult female each year constituted the difference between a stable and declining population (Knight and Eberhardt 1984). Given that mortality appeared to be inversely related to habitat productivity, effectiveness of management actions in reducing mortality rates could not be judged without accounting for habitat conditions. Regression analysis of the relationship between adult female mortalities (y) and HPS(x) yielded:

$$\hat{y} = (2.77 - 0.119X)^2; \text{S.E.E.} = 2.6;$$
$$P = 0.06,\ r^2 = 0.73$$

Given HPS = 6.88 for SEP-OCT of 1986, predicted adult female mortality was 3.8 (4). Observed mortality (2) was substantially less than the predicted level, although within the 95% prediction interval. This suggested that management actions were effective in reducing human-caused mortality of bears during 1986.

We were also able to examine area distribution of habitat productivity by apportioning habitat type areas according to season- and year-specific habitat productivity scores. As an example, seasonal distributions were calculated for 1986 as well as SEP-OCT distributions for 1979 and 1980 (fig. 5). The proportionate area of Yellowstone Park producing virtually no food (HPS < 1) increased from a low in APR-MAY to a high in AUG and SEP-OCT; on the other hand proportionate representation of the most

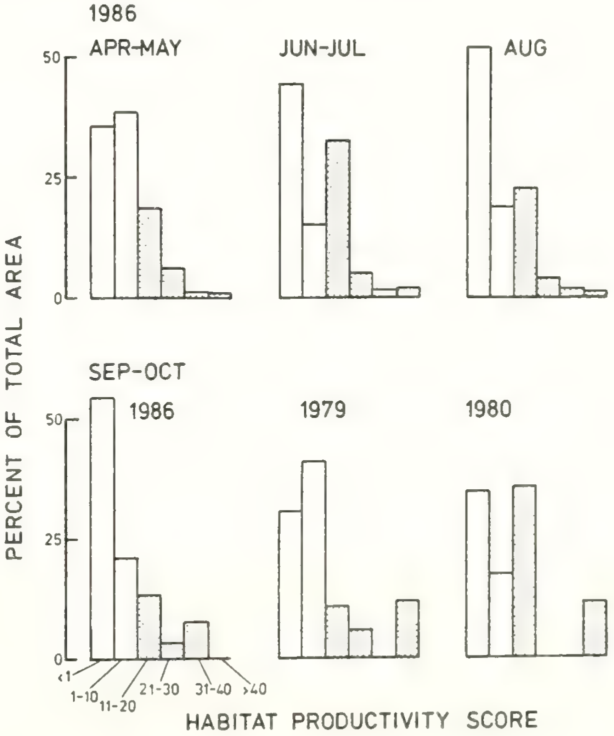

Figure 5--Seasonal habitat productivity score class, as a percent of total area in Yellowstone National Park, for 1986 and for September-October (SEP-OCT) of 1979 and 1980.

productive habitat (HPS > 30) was greatest in SEP-OCT. A comparative abundance of moderately productive habitat existed APR-MAY through AUG.

During fall of 1986 a limited area of highly productive habitat was available, compared to more productive years such as 1979 and 1980. Given that dominant animals (e.g., adult males) very likely preempted this productive habitat during relatively poor years such as 1986 (Mattson 1987), a large portion of the bear population had to make do with a comparatively restricted area of mediocre habitat in 1986; a key difference between 1986 and 1979-80 was the large proportion of habitat in moderately productive condition (>1 and <31) during 1979-80. Bears would have had much greater space to meet their energetic demands during these more productive years. Limited spatial representation of moderate to highly productive habitat further explained the large number of management trappings involving problem bears during 1986 (31) compared to absence of all such actions during years such as 1979 and 1980 (see table 2).

SUMMARY

We chose to employ habitat types in combination with successional cover types for habitat stratification and analysis. These classifications were comprehensive in their treatment of the landscape, well accepted by area managers and researchers, and developed according to general ecological principles.

We employed habitat types as a framework for describing productivity and use of habitat by bears and also as a foundation for evaluating distribution and variation of habitat productivity on much larger scales. These evaluations were, in turn, a basis for understanding bear behavior and population phenomena. We calculated mean productivity scores and their year-to-year variation as well as diversity of feeding activity for habitat types. Within-type variation in productivity was stratified by successional stage. Further refinement of habitat analysis below the level of habitat type and cover type was necessary and applicable to evaluation of foraging strategies and site-specific, human-induced impacts. Habitat types were a basis for analyzing distribution of bear habitat productivity with respect to environmental gradients and area and for calculating habitat productivity scores for Yellowstone National Park.

In short, habitat types served as a very efficient information storage and retrieval system and a legitimate basis for habitat analysis. This assessment is certainly qualified by idiosyncracies of the study area environment and the animal we studied: the relative heterogeneity of much of the habitats and comparatively simple successional pathways facilitated use of habitat types as we did. Also, a wide ranging animal such as the grizzly bear made a coarser stratification of the environment such as is provided by habitat types acceptable for large-scale analysis. A key part of using any ecological classification system for analysis of wildlife habitat, as we see it, is description of temporal and spatial variation within units. The ecological classification can be, in turn, a key tool in describing temporal and spatial variation of a large study area such as ours.

REFERENCES

Baker, Frederick S. 1944. Mountain climates of the western United States. Ecological Monographs. 14: 223-254.

Daubenmire, R.; Daubenmire, Jean B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, Washington Agricultural Experiment Station. 104 p.

Daubenmire, Rexford F. 1978. Plant geography: with special reference to North America. New York: Academic Press. 338 p.

Despain, Don G. 1983. Nonpyrogenous climax lodgepole pine communities in Yellowstone National Park. Ecology. 64(2): 231-234.

Despain, Don G. 1986. Habitat type and cover type as a base for grizzly bear habitat mapping and evaluation. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 230-233.

Hartigan, John. 1983. Cluster analysis of variables. In: BMDP statistical software: 1983 printing with additions. Berkeley, CA: University of California Press: 448-455.

Knight, Richard R.; Eberhardt, L. L. 1985. Population dynamics of the Yellowstone grizzly bear. Ecology. 66(2): 323-334.

Mace, Richard D.; Bissell, Gael N. 1986. Grizzly bear food resources in the flood plains and avalanche chutes of the Bob Marshall Wilderness. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 78-91.

Mattson, David J. 1984. Classification and environmental relationships of wetland vegetation in Yellowstone National Park, Wyoming. Moscow, ID: University of Idaho. 409 p. Thesis.

Mattson, David J. 1987. Habitat dynamics and their relationship to biological parameters of the Yellowstone grizzly bear, 1977-83. Bozeman, MT: Interagency Grizzly Bear Study Team; Progress Report. 28 p.

Mattson, David J.; Knight, Richard R.; Blanchard, Bonnie M. 1986. Derivation of habitat component values for the Yellowstone grizzly bear. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 222-229.

Mueggler, W. F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Romme, William H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs. 44(3): 549-558.

Shannon, Claude E.; Weaver, Warren. 1963. The mathematical theory of communication. Urbana, IL: University of Illinois Press. 117 p.

Steele, Robert; Cooper, Stephen V.; Ondov, David J.; [and others]. 1983. Forest habitat types of eastern Idaho-western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 122 p.

Weaver, John; Escano, Ron; Mattson, David; [and others]. 1986. A cumulative effects model for grizzly bear management in the Yellowstone ecosystem. In: Contreras, Glen P.; Evans, Keith E., compilers. Proceedings--grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 223-246.

Zager, P.; Jonkel, C.; Mace, R. 1980. Grizzly bear habitat terminology. Missoula, MT: Border Grizzly Project; Special Report No. 41. 16 p.

APPENDIX: HABITAT TYPE ACRONYMS AND DERIVATIONS

Acronym	
Feid/Agca-Gevi	Festuca idahoensis/Agropyron caninum-Geranium viscossissimum phase[1]
Wet Meadow	Phleum alpinum series[2]
Marsh/Fen	Carex rostrata, Carex aquatilis, and Carex vesicaria series[2]
Shaded Wetland	Calamagrostis canadensis series[2]
Artr/Feid-Gevi	Artemisia tridentata/Festuca idahoensis-Geranium viscossissimum phase[1]
Arca/Feid	Artemisia cana/Festuca idahoensis habitat type[1]
Psme(Abla)/Syal	Pseudotsuga menziesii (Abies lasiocarpa)/Symphoricarpos albus habitat type[3]
Pico/Putr	Pinus contorta/Purshia tridentata habitat type[3]
Abla/Caro	Abies lasiocarpa/Carex rossii habitat type[3]
Abla/Cage	Abies lasiocarpa/Carex geyeri habitat type[3]
Abla/Caru	Abies lasiocarpa/Calamagrostis rubescens habitat type[3]
Abla/Libo	Abies lasiocarpa/Linnaea borealis habitat type[3]
Abla/Vagl	Abies lasiocarpa/Vaccinium globulare habitat type[3]
Wet Forest	Abies lasiocarpa/Calamagrostis canadensis and Picea engelmannii/Equisetum arvense habitat types[3]
Abla/Thoc	Abies lasiocarpa/Thalictrum occidentale habitat type[3]
Abla/Vasc-Vasc	Abies lasiocarpa/Vaccinium scoparium-V. scoparium phase[3]
Abla/Vasc-Pial	Abies lasiocarpa/Vaccinium scoparium-Pinus albicaulis phase[3]
Pial/Vasc	Pinus albicaulis/Vaccinium scoparium habitat type[3]
Abla-Pial	Abies lasiocarpa/Arnica cordifolia, Abies lasiocarpa/Ribes montigenum, and Abies lasiocarpa/Juniperus communis habitat types[3]

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[1] Mueggler and Stewart 1980

[2] Mattson 1984

[3] Steele and others 1983

HABITAT TYPES AS A VEGETATION MANAGEMENT TOOL

Wendel J. Hann

ABSTRACT: The habitat type system developed by Daubenmire has been implemented and tested in vegetation management. This system has proved to be as valuable in nonforest as in forest ecosystems. Some problems have occurred as the system has been developed and implemented. These problems can be solved through improvements and increased training. Major improvements can be made in the ability to predict response of vegetation and environmental effects to various management practices. The habitat type classification system provides a critical framework for development and improvement of this predictive capability.

INTRODUCTION

Habitat types (Daubenmire 1952) provide the basic framework for design of vegetation management prescriptions. This system of classification has proved to be very effective, yet some problems have developed in application. Problems with broad variability within types and misidentification of habitat types have reduced accuracy of predictions of vegetation response, productivity, and environmental effects. These problems can be reduced by refining classifications, increasing our understanding of causal variables, and training people to improve their identification abilities.

Inventory of existing and potential vegetation, along with physical parameters, is a basic foundation for evaluating and designing vegetation management practices. The ability to predict response to various alternatives is fairly limited, if all that is available is a prediction of the potential vegetation. Succession and environmental effects models, stratified by habitat type, provide the type of system that is needed to adequately evaluate a range of alternatives. Linkage of inventory data, prediction models, and spatial relationships on computer systems make it possible to rapidly and efficiently analyze a broad range of alternatives.

The evaluation of alternatives and design of prescriptions occurs at two levels. An evaluation of vegetation response and site specific environmental effects can be made at the stand level. Larger scale evaluations of cumulative effects, mosaic diversity, and resource levels are done at the area level. Habitat types have provided a framework for communication, information storage, and stratification of response predictions. This framework is a critical part of the stand and area vegetation management process.

APPLICATION OF CLASSIFICATIONS AND DEFINITIONS

Interpretation of Definitions

In order for vegetation managers to fully utilize habitat types, they need to understand the basic process of classification development. The investigator that develops a habitat type classification is integrally involved. Consequently, the concepts and process related to the habitat type classification should be clear to the investigator. This process, and the limitations, may not be clear to managers that are attempting to interpret the classification to predict vegetation response, productivity, and value for various resource uses.

The primary objective for development of the habitat type classification is to describe the potential plant communities that occur on various environments of the landscape. This is accomplished by searching for communities that are considered, by the investigator, to be expressions of the potential for a site. These communities are those that are considered to be at the endpoint of secondary succession, have a stable species composition, and are in equilibrium with their environment (Barbour and others 1980; Daubenmire 1968; Mueller-Dombois and Ellenberg 1974).

Communities are described by sampling macroplots, within each community, and an analysis is used to group similar macroplots into an aggregate that represents a community type. The average of the sampled macroplots in the type is used to describe the vegetation and environmental attributes. Plant species that consistently occur in the type are used as indicator species to assist in identifying the community type. A "community type" includes all the communities that have similar species composition and is identified by one or more indicator species. The community type classification can be used for both the

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Wendel J. Hann is Regional Ecologist for the USDA, Forest Service, Northern Region, Missoula, MT.

potential community or seral communities. In the case of the habitat type classification, the potential community type is classified to assist in identifying the potential for a type of site or land.

A habitat type is "all the area (sum of discrete units) that now supports or within recent time has supported and presumably is still capable of supporting one plant association" (Daubenmire 1952; Daubenmire 1968). An association is the climax or potential community type. For application, all the land or sites that have the capability to support one potential community type make up one habitat type. Each site has an environment in which the combined effects of the soil, climate, aspect, slope, elevation, and other physical parameters produce a potential community.

The indicator species for a potential community type usually have a fairly broad ecological amplitude and, thus, occur across a wide range of sites or environmental conditions. Compensating environmental factors can produce the same plant environment on sites that have very different individual factors. For instance, the same potential community type can occur on two different sites within one geographic area; one site that is a high elevation, steep south slope, with excessively-drained, gravelly soils on limestone parent materials; the other site that is low elevation, gently rolling, with well-drained loamy soils on sandstone parent material. Changes in geographic area that create different climates also can produce very different site conditions that will support the same potential community type. Consequently, the habitat type usually contains considerable variability in combinations of environmental factors.

To reduce this variability, an additional indicator species is often used to split the habitat type into phases (Pfister and others 1977). However, even at the phase level there is often considerable environmental variability within the type. This variability can be reduced by splitting the potential community type into ecological types, using geographic area, soil characteristics, and topographic classes. An ecological type includes all the land or sites that have the capability to support one potential community type, and have relatively uniform climate, soils, and topography such that their ability to produce vegetation and respond to management is similar (Stewart and Hann 1983; USDA Forest Service 1986; Hann and Jensen 1988).

Other classification systems have been developed that are based on the same concept of identifying land that will support one type of potential community. The range site classification system was developed for areas with nonforest potential (USDA Soil Conservation Service 1976). Sites are grouped based on their productivity and type of potential community, and are typically named for their soil texture, soil depth, and/or place in the landscape. Consequently, the range site, in definition, is similar to the ecological type. However, in actual use, there is often more than one type of potential community included within a range site, due to problems with disturbance and a lack of adequate samples on undisturbed sites. An additional problem is that there is often only one macroplot sample used to describe the modal concept of the range site. This approach does not describe the variation within the range site and can lead to errors in interpretation.

An ecological problem with the basic definition of the range site classification is its restriction to rangeland ecosystems. From a conceptual viewpoint, an ecological land classification should be appropriate in both rangeland and forest ecosystems. The term ecological site has been used by the Bureau of Land Management in a similar manner to the range site.

Identification and Variability

The field identification of habitat types, by personnel conducting inventories, is often more difficult than development of the classification. Most communities in the northern Rocky Mountains, Great Plains, and Great Basin have been disturbed and are not at the endpoint of secondary succession, do not have a stable plant species composition, and are not in equilibrium with their physical environment. These communities are seral communities. A majority of the western landscape supports plant communities that are in this condition, due either to natural or human-caused vegetation disturbance. This situation is not necessarily negative. In many cases a seral community is the desirable situation for natural diversity, ecosystem management, and productivity.

The typical habitat type classification is based on pristine sites that can be found within the geographic study area. The investigator searches the geographic area for undisturbed sites that express the potential and uses data collected from these sites to develop the classification and identify indicator species. The average species floristics and composition for each type are given to represent the type. Most classifications include a cursory evaluation of site characteristics and the physical descriptions typically describe the aspects, elevation zones, slopes, climatic influences, and broad soil characteristics of the type. Very few classifications attempt to classify the site variability into ecological types within the habitat type or to identify the seral patterns in relation to type of disturbance. This typical process contains some inherent problems that often make it difficult for field personnel to accurately identify the habitat type, or can lead to misinterpretations about the type. These problems are summarized in the following four points:

1. Biased sampling. Most investigators only sample those sites that are considered pristine or relatively similar to the potential for the site. Consequently, there is a fairly high probability that there will be types that are not classified because sample selection is biased towards communities that are

undisturbed. Certain types exist where there are no examples of the vegetation potential for the site, since all of the communities within the type are disturbed, or have not had adequate time to stabilize. Sampling is also often biased towards the investigators' preconceived ideas for the modal concept of the type. Communities that do not fit this modal concept, ecotones, and unique situations are usually not sampled. The result of a classification with missing types, when used for inventory and interpretation, is a misidentification or a land stratification that does not fit in the framework. Misidentification can cause errors in interpretation, while the inability to name a given piece of land creates a gap in our ability to predict potential and response to management.

2. Variability. Presence of one or more indicator species is typically used to identify a type. The amplitudes of the communities these indicator species occur in are usually very broad in variability of species floristics, composition, and environment. Most habitat type classifications do not have adequate samples to describe this variability. Since species floristics and composition do not have a normal distribution across a type, any one community has a fairly high probability of being very different from the average. Most classifications emphasize that, in addition to using the key, the user should always compare the community to the species list and average composition for the type to assure that it is similar. In a stand that is disturbed and has only low or moderate similarity to the potential, where an adjacent undisturbed stand in the same environment is not available, this comparison may not be meaningful. Consequently, accurate identification of a type where the vegetation has only low or moderate similarity to the potential may be very difficult if the investigator has not developed a reliable environmental model that predicts the potential based on climate, soils, and topography. Although a community may fit the general description for the type, the indicator species may not be present. Field personnel often misidentify these situations by placing too much emphasis on presence or absence of indicator species.

3. Accuracy of interpretations. Interpretations from the classification relative to vegetation composition, production, response to disturbance, and environmental characteristics are based on the data collected to develop the classification. Very few classifiers collect additional data to test the variability of types, or to add to the ability to predict response and environmental parameters. Consequently, predictions that use an average, or even a range, may have very low reliability due to the large amount of variability and minimal sampling.

4. Correlation with other classification systems. There is often confusion in discussion of correlation of land classification systems versus correlation of plant species or environmental factors. Various investigators have argued for or against the concept that there is a correlation between soils and habitat types. The problem with this argument is a lack of separation of environmental factors from soil classification. Those investigators that have tried to use soil classification at the series, family, or more general levels to make direct correlations with habitat types were usually unsuccessful. The attributes used for soil classification at those levels do not provide explanation at the level that would correlate with a potential vegetation type. However, the correlation is usually very high for those investigators that split soil series into phases using aspect, slope, elevation, landform, geographic climatic area, soil surface texture, and other environmental variables that are highly correlated with plant species occurrence and distribution.

The problems that have developed from our typical process of classification of potential communities should and can be corrected. Since the habitat type classification identifies land that produces types of potential communities, it is a land classification. The process of classification should involve sampling of the physical environment at an equal level to sampling of the potential communities. If different types of physical environments are found, for which no communities can be found that are similar to the potential, then they should be sampled, indicator species identified, and the community type that is furthest developed towards potential used to identify the type. This process will help avoid missing types due to a lack of undisturbed communities.

Habitat types should be further split into ecological types based on site factors that influence vegetation production and response to management. Sampling should be adequate to describe each type of site within the geographic study area. While classifying site potential, it may also be appropriate to classify seral stages and community types for each ecological type. An understanding of the communities that result from different types of disturbance will help identify the potential for the type of site. This process will reduce variability and improve accuracy of interpretations.

There are some common errors in understanding of the habitat type system that affect accuracy of identification. These types of errors can be corrected by proper training of field personnel. These errors are summarized in the following three points:

1. A common problem that causes errors in identification is the idea that personnel only need to be trained to identify the indicator species in order to identify the type. If they cannot identify the other common species in the type, they cannot confirm identification by comparing the species floristics and composition of the community to be identified with the average for the type.

2. Personnel using the classification key without proper training often select the dominant species to use as the indicators. This often causes an error in identification since species are not evaluated that have decreased due to disturbance, are of younger age and/or smaller size, or are not yet present in the

community because it is in an early successional stage. A common error in forested communities is to pick the tree indicator species that is in the overstory rather than the more tolerant, later successional tree species coming up in the understory. These understory species are usually indicators of the true potential. A common error in nonforest communities is to pick the dominant shrub and/or grass as the indicator species and not look for species that have been depleted due to grazing. These species may often be found under a shrub overstory where they are protected from grazing or as remnant individuals in the community. A properly constructed key that organizes species and types from moist to dry, tolerant to intolerant, desirable to undesirable, and gives clues on what to expect in disturbed conditions, will help avoid this problem.

3. Personnel that are not trained in identification of plants to the level required by the classification will misidentify indicator plants and other common plants and, thus, misidentify the type. The habitat type guide, manual or instructions should specify the plant species and level of identification ability needed to properly use the classification.

Inventory--Mapping, Sampling, and Summary

In order to evaluate vegetation management alternatives and predict response, an inventory of both the site potential and existing vegetation is needed. Common inventory systems have involved mapping of habitat types, soil types, and cover types. As seral community type classifications are developed by habitat type, the combination of community type/habitat type can be mapped. Map delineations of stands can also be sampled by replicating plots where specific vegetation or site attributes are measured. The average and variation of these measurements can then be used to describe the stand. A complete inventory of delineated stands will usually involve mapping of soil type, habitat type, and cover type, along with sampling of specific attributes that need to be statistically described, such as size and density of trees or forage production.

A problem consistently encountered when mapping vegetation and soils is the complexity of variation versus the smallest delineation allowed by the map scale. When delineating vegetation stands on a map, the true complexity of communities and their environments can usually not be mapped because the map scale is too small to allow delineation. Consequently, within one vegetation stand delineation, there may be more than one habitat type, soil type, and/or existing community type. This is not a problem if the stand can be sampled and data analyzed in a manner that describes this variation.

An important part of the inventory process is the provision for objectives and standards. Inventories should be designed to meet specific information and decision-making needs. The inventory system should provide a consistent approach and format and have standardized codes and measures of accuracy. In the Northern Region of the Forest Service there are two systems that provide consistency in data format and accuracy. These include the Stand Exam Procedures chapter of the Timber Management Data Handbook (USDA Forest Service, 1985) and the Ecodata chapter of the Ecosystem Classification Handbook (Hann and Jensen 1988). The Stand Exam system provides standards and format for plot data of tree measurements, and the Ecodata system provides standards and format for plot data of vegetation and site measurements. There are standard computer data entry, analysis, and prediction programs as complements to both these systems.

The advent of computers, with large storage and analysis capability, that have "user-friendly software," has made the analysis and display of large amounts of data a relatively easy task. This capability allows managers to be able to evaluate many different vegetation and site attributes for many stands and many alternatives. The implementation of computer based geographic information systems (GIS) will automate the display of inventory data and predictions with the spatial map relationships.

An important consideration for the design of an inventory system is the collection of data in a manner that facilitates description of the existing conditions and provides data for developing classifications, predictions, and records of history of treatment. A system that provides information for both types of uses increases efficiency and significantly reduces the cost of improving classifications and management implications. An example is the Northern Region's Ecodata plot system (Hann and Jensen 1988). The same plot data can be used to describe existing vegetation composition, develop a prediction for vegetation response to a type of treatment, classify a community type, determine similarity to the site potential, act as the starting point for a succession model prediction, and be used for comparison of rate of change when remeasured at a later date.

Another important aspect of inventory is the use of extrapolation. Due to the need for information on all delineated stands within an area and the lack of resources to accomplish a complete ground inventory, general data for many stands are often extrapolated. A common extrapolation technique involves estimates by personnel experienced in the area associated with evaluation of aerial photographs, map data, and ground data from stands that have been visited. A second technique involves sampling selected stands of each photo interpretation cover type/landscape stratification and applying the average of various resource and environmental attributes to all stands in the class. A third technique is to select stands to sample in each cover type/landscape stratification, and use these data to develop a multivariate regression prediction of resource and environmental characteristics.

VEGETATION MANAGEMENT PREDICTIONS

Predictions Based on the Classification of Potential Communities

Although the habitat type or ecological type classifications provide an important tool for land stratification and mapping, their application for predicting response to management is limited. A basic classification of potential vegetation provides information on: (1) the composition and productivity of the potential community type; (2) the values of the potential community type for various resource uses; (3) site characteristics of the type; and (4) hydrologic and climatic averages for the type. Very little can be gleaned from many of these classifications on how the vegetation will respond to different types of disturbance, management treatments, and rate of change over time or how the soil and hydrologic characteristics will vary with different management practices.

The most important use of the basic site potential classification is as a framework for communication, storage of information, and stratification to measure response. The classification provides a relatively uniform situation that people can visualize and talk about. It also provides a class where productivity and response is narrow enough in variability that causal factors can be identified. When the class is found to be too broad for evaluating productivity or response, it can be further stratified using environmental characteristics.

Predictions Based on Seral Classification and Modeling

In order to use a habitat type classification as a tool for prescribing vegetation management practices, predictions need to be made for vegetation response. The succession classification and modeling systems developed by Huschle and Hironaka (1980), Steele (1984), Arno and others (1985), and Keane (1987) are the type of prediction systems needed to adequately evaluate vegetation response alternatives. These systems describe vegetation composition, productivity, and rate of change in response to various natural and human-imposed treatments. In forested communities, these systems in combination with a forest growth and yield model (Stage 1973; Wykoff and others 1982) provide a predictive process that managers can use to evaluate treatment response prior to implementation. For nonforest communities, productivity measurements must usually be stratified by seral community type and rates of change are much more difficult to predict.

In addition to being able to predict vegetation response to various treatments, managers need to assess effects of treatment and vegetation change on soil, water, air, and animals. Volumes of literature are available that summarize or give predictions for various conditions. The large amount of literature on treatment effects, and the often conflicting results, make it difficult for managers to develop reliable predictions. A systematic, efficient process is needed for predicting effects. A computer model that accesses the basic inventory data, interacts with the user to consider treatment options and conditions, and predicts response based on tested relationships would be a desirable solution to this need. The Intermountain Forest Service's Research Station has been very active in development of these types of models for predicting fire effects and behavior, impact of various treatments on soils, and hydrologic response to different treatments. The Northern Region of the Forest Service has been implementing these models through various computer applications for field use by managers.

VEGETATION MANAGEMENT

Stand Level Evaluations

At the stand level of evaluation and prescription, variation in vegetation and site characteristics is relatively low. However, even at the stand level, there are often contrasting vegetation communities and soils, due to a complexity of variation that cannot be mapped. In these situations very different responses can come from the same treatment, within the same stand.

For analyzing response of vegetation, site characteristics, and resource values, there is a basic set of information that is needed:

1. A basic inventory of the composition and values of the existing vegetation and a prediction of the potential vegetation.

2. Information on the soil and hydrologic characteristics, their limitations, and their effects on productivity.

3. Identification of alternatives that are acceptable from both the biological and economical standpoints.

4. A prediction of the response of the vegetation over time and the effects on resource values of each alternative.

5. The value of different resource trade-offs, products, and effects related to each treatment.

From this basic set of information, managers can assess treatment alternatives for a stand, across a reasonable range of alternatives. This is a process that not only meets multiple-use requirements for public land management, but is a sound biological and economical method for evaluation of management of land, regardless of ownership.

Area-Level Evaluations

An evaluation of alternatives that has only considered the response and effects at the stand level is usually not adequate from an ecological and multi-resource perspective. Although vegetation and site characteristics may be somewhat uniform and response can be predicted at the stand level, this is not the case for larger scale effects on water, animals, soil, air, diversity, and resource outputs. An area level of analysis that evaluates resource trade-offs, products, and effects across all stands is needed to make these types of assessments. "Cumulative effects analysis" is a term used for evaluating effects on a resource of many impacts, over time, within a biologically defined geographic area.

Area evaluations are designed to analyze alternative management practices for stands that are to be actively managed and evaluate vegetation dynamics for stands that will not be treated. When considering an area that contains several hundred stands, it is readily apparent that this can be a very complex and confusing analysis of alternatives, relative to predicted outputs and effects. The use of computers is almost a necessity to manage the data and evaluate various combinations of stand treatments.

HABITAT TYPES--THE KEY TO ORGANIZATION

Without a classification that defines potential, no two managers can communicate on the same level concerning site potential and stratification of vegetation response. Managers, without a classification of potential, usually build a framework based on existing vegetation. We have many examples that demonstrate the problems resulting from basing predictions of productivity and response on a framework that keeps changing and is not stratified by the physical environment.

The habitat type classification has provided a framework for communication, information storage, and ecosystem stratification. Dr. Rexford Daubenmire and those authors that have followed him deserve full credit for providing a system that continually leads to improved understanding of vegetation dynamics.

REFERENCES

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 74 p.

Barbour, M. G.; Burk, J. H.; Pitts, W. D. 1980. Terrestrial plant ecology. Menlo Park, CA: The Benjamin/Cummings Publishing Co. Inc. 604 p.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22: 301-320.

Daubenmire, R. 1968. Plant communities, a textbook of plant synecology. Harper & Row, New York: 300 p.

Hann, W. J.; Jensen, M. E. 1988. Chapter 4-ecodata sampling methods, ecosystem classification handbook. Region 1 Supplement to Forest Service Handbook 2090.11. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 400 p.

Huschle, G.; Hironaka, M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33: 179-182.

Keane, R. E. 1987. Forest succession in western Montana--a computer model designed for resource managers. Res. Note INT-376. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York: 547 p.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Stage, A. R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

Stewart, W. L.; Hann, W. J. 1983. Classification of shrub steppe habitat in the northern Rocky Mountains. In: Proceedings of the workshop on southwestern habitat types, April 6-8, 1983. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 11-20.

USDA Forest Service. 1986. Ecosystem classification, interpretation, and application. Forest Service Manual 2060. Washington, DC: U.S. Department of Agriculture, Forest Service. 4 p.

USDA Forest Service. 1985. Chapter 400--stand exam procedures. Region 1 Forest Service Handbook 2409.21h. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 250 p.

USDA Soil Conservation Service. 1976. National range handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 150 p.

Wykoff, W. R.; Crookston, N. L.; Stage, A. R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

RANGE SITES/ECOLOGICAL SITES--

A PERSPECTIVE IN CLASSIFICATION AND USE

Stephen G. Leonard and Ray L. Miles

Abstract: The site climax concept, differentiations between sites, and present vegetation are discussed as they relate to range site classification and as they relate to ecological site, habitat type and community type classifications now in use. Range site and ecological site classifications provide one level of classification that are not necessarily mutually exclusive nor incompatible with habitat types and community types. Range sites/ecological sites, habitat types, and community types represent different levels of classification with different interpretational values that conceptually could be integrated into a universal classification system for vegetation communities. More important than the individual classification or their potential compatibility, however, is the need for a unifying force to establish a universal classification or taxonomy. The National Cooperative Soil Survey provides a precedent that may be helpful.

INTRODUCTION

The susceptibility of vegetation to change in short periods of time as compared to soils has presented a dilemma for vegetation classification depending on the level and kind of management interpretations desired from classification. Two general types of vegetation classification are in use, one based on climax or natural potential vegetation and the other on present vegetation. One addresses the capability of a site to produce vegetation in a natural situation while the other addresses current site production. Neither, alone, may adequately address the needs of management to identify objectives and possible solutions to problems.

Two of the most prominent classifications used in the United States are range sites (Dyksterhius 1949; Renner and Allred 1962; Shiflet 1973) and habitat types (Daubenmire 1970; Hironaka and others 1983; Mueggler and Stewart 1980). Both are based on the climax plant community concept. Community type classifications (Mueller-Dombois and Ellenberg 1974) are often used for present vegetation. Range condition, in context with range sites, is also a classification of present vegetation. The fact that no universally recognized classification or taxonomy has evolved for organizing, evaluating and communicating information about vegetation communities has seriously impaired our ability to extrapolate data for resource management and for applied research activities. The term ecological site was proposed by the Range Inventory Standardization Committee (RISC) (1983) and essentially used range site concepts to include natural ecosystems other than rangelands. The Bureau of Land Management (BLM) (USDI 1984) describes the term ecological site as synonymous with range site on rangelands and stated that the concept also applies to grazeable woodlands and forest sites, but there was no consensus among other classifiers.

Even if there is eventually agreement among classifiers on terminology and general concepts such as those proposed by RISC, there still needs to be a continuing process for expanding the classification as new information is obtained and for reconciling differences among classifiers. We hope that the following discussion on some aspects of range sites and their relationship to other classifications will reemphasize the fact that the ecological concepts involved are not that irreconcilably different, or at the least, not mutually exclusive. We submit that a precedent exists in Soil Taxonomy that can serve as a model to establish a standard vegetation community classification and taxonomy that meets management needs.

THE CLIMAX CONCEPT

The concept of climax gives the range site (and habitat type) concept an inherent utility but it is also one of the greatest sources of criticism. The use of the climax concept allows identification of repeatable landscape units and their associated soils and related present vegetation communities with capability to produce similar kinds, amounts, and proportions of vegetation at the presumed end-point of succession. It follows that similar landscapes should respond comparably to like management, thus providing a tool to reasonably predict and extrapolate management responses, the effects of natural phenomenon

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Stephen G. Leonard is Range Scientist, Bureau of Land Management member of the National Soil-Range Team, Reno, NV; Ray L. Miles is Soil Scientist, Soil Conservation Service, West National Technical Center, Portland, OR, (Former SCS member of the National Soil-Range Team).

(fire, drought, etc), research information, and monitoring results. By quantifying and describing the associated soil, landscape and climate features, the site and, therefore, the management potential can be identified with reasonable accuracy even in the absence of vegetation (Shiflet 1973).

But how do we identify climax vegetation in the first place? The National Range Handbook (NRH) (USDA 1976) provides these methods:

(a) "Evaluation of relict vegetation and associated soils . . ."

(b) "Interpolation and extrapolation of plant, soil, and climatic data from existing relict areas along a continuum . . . ."

(c) "Evaluation and comparison of areas currently grazed . . . with similar areas that are not grazed . . . ."

(d) "Evaluation and interpretation of research data . . ."

(e) Review of early historical accounts and botanical literature of the area.

RISC gives us the same methods verbatim to identify the "Potential Natural Community" (PNC) except for item (c) wherein logging and other disturbances are considered in addition to grazing. The term PNC was apparently intended to encompass the climax concept, but makes allowance for the loss or gain of species. However, neither method includes any specific criteria for establishing exactly what constitutes climax. Meeker and Merkel (1984) reviewed five different climax theories. They recommended the site climax theory as used in the range/ecological site concepts, but did not identify specific criteria. Some have asked if long term stability represents climax. Walker and others (1981) present a convincing argument that at least two stable points exist for many sites. Passey and others (1982) stated "Remnants of climax vegetation are scarce in most western rangeland areas. Thus, approximation of the probable plant-community potential for many sites has necessarily been empirical."

So just how do we determine climax? Dr. Harold Heady (1984) remarked that it is impossible to prove or disprove climax except by one's own definition and that the purpose of range sites is to provide an inventory for land management and not to prove succession and climax. It is also our opinion that climax is most often determined by one's own definition. It is an opinion based on the state of knowledge and available research. The agencies have sometimes modified the opinion process through a hierarchy of responsible individuals and developed policy for site description format and a correlation process. This process provides a desirable process for incorporating additional information and provides more consistency in the site descriptions. The community portrayed is none the less an opinion, either from a consensus or occasionally based on the perception of a dominant personality within an agency. While this has been the major source of controversy, it is one which ecologists can and should resolve. Unfortunately, there is no formal process in place for reconciling differences between agencies, university affiliates and other classifiers. Fortunately, the utility of the site concept is not necessarily dependent on the absolute knowledge of observed climax even though we strive for this. The climax community description can be, and often is, revised as additional research and information becomes available (USDA 1985).

The climax plant community concept is often confounded by user needs, management considerations and individual preferences for establishing significant differences between plant communities. It isn't any wonder we are sometimes confused about what we are classifying.

SEPARATING SITES

It is important for a classification system, and to the user of basic resource data, to have consistent and standard criteria for separating and distinguishing between climax plant communities.

Criteria outlined in the National Range Handbook are as follows:

(a) Significant differences in the species or species groups that are ecological dominants in the plant community.

(b) Significant differences in the proportion of species or species groups that are the ecological dominants of the plant community.

(c) Significant differences in the total annual production of the plant community.

Any differences in criteria (a, b, and c), either singly or in combination, great enough to indicate a different use potential or requiring different management, such as different grazing systems, season of use, or stocking rate, are basis for establishing a range site (USDA 1976).

Habitat types are separated on the basis of dominant (and sometimes co-dominant) species within the climax community. Other criteria, e.g. production or composition, can be used to identify habitat type phases. The habitat type is a higher level classification with less specificity than a range site but maintaining the climax concept. A habitat type phase may be practically synonymous with a range site.

RISC proposed adding differences in soil properties, slope or topographic factors reflecting different use potentials not reflected in the plant community as criteria for differentiating sites. The authors take exception to this proposed classification criteria since it is not ecologically based. If the individual soils and associated landscape factors have been truly correlated with the site, the management differences referred to can be accounted for in soil and map unit interpretations. The only exceptions would occur when the soil or landscape is altered through erosion, mass wasting, and so forth, as reflected by the plant community.

The use of annual biomass production to quantify vegetation attributes and differentiate between sites has both advantages and disadvantages. No other attribute quantifies the consumptive value of vegetation, for grazing, wildlife forage or wood products, as well as production. Production, however, is difficult to measure with statistical precision or accuracy. Production can also be extremely variable over time, but at the same time, knowledge of the expected yearly or seasonal variability is a valuable attribute to consider in long range planning and management

Production is also an important attribute when considering condition and trend. Differences in production due to declines in plant vigor or available moisture caused by changes in soil surface characteristics (Rauzie and others 1968) can be indicative of downward trends prior to changes in basal cover or frequency of species. This is not to say that other attributes do not have additional interpretative value. Ecological sites could be classified using attributes such as cover but they would have only interpretative values associated with those parameters. A description of a combination of attributes would undoubtedly be best for interpretative purposes as well as for adequate classification.

Regardless of the criteria, the interpretation of "significant differences" depends on whether one is a "lumper" or a "splitter". Significant difference is used to describe the degree of difference for management purposes and not the degree of accuracy in the statistical or scientific sense. There is a good reason for this. As stated in the NRH, a 100 pound difference in average annual production between arid sites capable of producing only 200 to 300 pounds per acre might be considerably more significant than the same difference between sites producing 2,000 pounds per acre. The inconsistencies, however, have prompted the proposal of some additional criteria for determining what is "significant" in the site correlation process developed by the National Soil-Range Team. This process and a standard site description format as well as establishing a quality control method, are being evaluated in a four-state test.

PRESENT VEGETATION AND RANGE CONDITIONS

Range condition (USDA 1976) is determined by the coefficient of community similarity between a present community and the climax, using either the absolute production of individual species or relative compositions of the total production. The community is then classified into one of four range condition classes determined by 25 percent increments of community similarity.

RISC also proposed four classes of present vegetation, but based these on a coefficient of community similarity to the PNC. These classes are collectively referred to as "ecological status".

Community types are an aggregation of individual communities based on similarity of specific attributes such as species composition of cover, production, structure, etc. Huschle and Hironaka (1980) discussed the need for a community type classification and proposed a model for relating community types to a probable secondary successional pattern within habitat types. Leonard and others (1987) have also discussed the need to identify seral community types for more specific interpretations relating to range sites and range condition classes.

A PROPOSAL

Different levels of classification become apparent when comparing present vegetation to the site climax community (actually site climax community type in most cases). All have value depending on the level of interpretation desired. Hironaka (1986) proposed a unifying scheme giving land managers the benefit of three levels - community type, range site (or ecological site) and habitat type. Range condition classes or ecological (seral) status could be easily integrated in this scheme. It seems immensely profitable to combine our knowledge gained through use of each system. So why doesn't this happen?

Although there might be some initial "fit" problems (the boxes we have constructed independently for classification may have to be shifted a bit to accommodate overlaps or gaps between systems), there appears to be no technical reason why this couldn't be done. It appears to be related more to human nature. Agency or personal "pride of ownership" is one hurdle. Comfort with a system we have already learned is another. We could continue on with a list of possible "excuses" that impede progress, but the compatibility of existing systems or even human nature may not be the biggest reason. Probably the paramount reason is the lack of a unifying force for vegetation classification and interpretation in the broader sense. The unifying force must come from, and involve, the major users of vegetation classification systems. Their continued involvement is imperative.

The situation is not unlike that experienced by pedologists prior to the formation of the National Cooperative Soil Survey (NCSS). The NCSS was formed without a charter (still) by a loosely organized group of professionals that recognized the need to maintain consistency in soil classification, correlation mapping, and interpretation and to discuss and propose needed changes or additions in classification and interpretation. The NCSS is independent of the professional organizations, the Soil Science Society of America and the Society of Soil and Water Conservation. The NCSS is now represented by each participant involved in soil survey and by the land grant universities. It is structured by state, regional and national levels so that issues can be dealt with at the appropriate level. The process of change is slow because of the complexity and size of the organization but there have been over 150 changes to Soil Taxonomy (USDA 1975) over the last ten years. The very existence of a National Soil Handbook and a revised manual is proof that it works. While the agencies and universities as cooperators have obligated themselves to the accepted standards, they still have the opportunity to propose and, subsequently, implement change.

If we are to achieve substantive progress, we must forget all the excuses and pull together to form a National Cooperative for Vegetation Classification and Interpretation. We can mutually benefit from each others experience and knowledge irregardless of agency affiliation or professional interest (range, forestry, botany, etc.). We need to start by identifying user needs and objectives, then tailor classification to meet these needs. Representatives from NCSS have expressed their willingness to share information about their organizational efforts and procedures. Yet, those of us involved with classifying natural plant communities must reciprocate by pledging our determination to undertake and sustain an equivalent effort. Now is the time to act.

REFERENCES

Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agricultural Experiment Station. Tech. Bull. 62: 131 p.

Dyksterhius, E.J. 1949. Condition and management of rangeland based on quantitative ecology. Journal of Range Management. 2: 104-115.

Heady, H.G. 1984. Range management from 1934 to 1984. In: Proceedings, national celebration - 50th anniversary of the Taylor grazing act. Grand Junction, CO: U.S. Department of Interior, Bureau of Land Management: 48-50.

Hironaka, M.; Fosber, M.A.; Winward, A.H. 1983. Sagebrush-grass habitat types of southern Idaho. Bulletin No. 35. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 44 p.

Hironaka, M. 1986. Habitat type, range site, and community type. In: McArthur, E. Durant; Welch, Bruce L., compilers. Proceedings-symposium on the biology of Artemesia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 15-18.

Huschle, Gary; Hironaka M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33(3): 179-181.

Leonard, S.G.; Miles, R.L.; Eshelman, K.R.; Wagner, R.E. 1987. A method to display seral community types for multiple use management. In: Abstracts of papers presented at the 40th annual meeting. Society for Range Management. Abstract.

Meeker, D.O., Jr.; Merkel, D.L. 1984. Climax theories and a recommendation for vegetation classification - a viewpoint. Journal of Range Management. 37(5): 427-429.

Mueggler, W.F.; Stewart, W.L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, Ut: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Mueller-Dombois, Dieter; Ellenberg, Heinz. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Passey, H.B.; Hugie, Vern K.; Williams, E.W.; Ball, D.E. 1982. Relationships between soil, plant community, and climate on rangelands of the Intermountain West. Tech. Bull. No. 1669. U.S. Department of Agriculture, Soil Conservation Service. 123 p.

Range Inventory Standardization Committee. 1983. Guidelines and terminology for range inventories and monitoring. Unpublished report on file at: Society for Range Management, Denver, CO. 13 p.

Rauzie, Frank; Fly C.L.; Dyksterhius, E.J. 1968. Water intake on midcontinental rangelands as influenced by soil and plant cover. Tech. Bull. No. 1390. Washington D.C.: U.S. Department of Agriculture, Agricultural Research Service and Soil Conservation Service in cooperation with Wyoming Agricultural Experiment Station. 58 p.

Renner, F.G.; Allred, B.W. 1962. Classifying rangeland for conservation planning. Agric. Handb. 235. Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service. 48 p.

Shiflet, Thomas N. 1973. Range sites and soils in the United States. In: Arid shrublands-Proceedings of the third workshop of the United States/Australia rangelands panel; 1973 March 26-April 5; Tucson, AZ. [Place of publication unknown]. 26-33.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil Taxonomy. Agric. Handb. 436. Washington, D.C. 455 p.

U.S. Department of Agriculture, Soil Conservation Service. 1976. National Range Handbook NRH-1. Washington, D.C. Section 300.

U.S. Department of Agriculture, Soil Conservation Service. 1985. National Range Handbook, 190-VI, Notice-5. Washington D.C. 5 p.

U.S. Department of Interior, Bureau of Land Management. 1984. BLM Manual Handbook H-4410-1-National Range Handbook. Washington, D.C. 21 p.

Walker, B.H.; Ludwig D.; Holling, C.S.; Peterman, R.M. 1981. Stability of semi-arid savanna grazing systems. Journal of Ecology. 69: 473-498.

DEVELOPMENT OF FORAGE RATING GUIDES FOR MONITORING RANGELAND CONDITION AND TREND

Leonard A. Volland

ABSTRACT: The concepts of forage monitoring and resource value rating have been proposed by the range management profession. One particular resource value rating, forage rating guidelines, is derived from plant association information and includes nonforest, forested vegetation, and community types dominated by non-native perennial species. The guidelines incorporate the effects of tree and shrub canopy closure on understory vegetation. The place of forage rating in the estimation and interpretation of trend is discussed.

INTRODUCTION

Range condition has been defined in two ways. Condition can be defined as the current productivity of a range relative to what that range is naturally capable of producing (Society for Range Management 1974). Range condition is also defined as the degree that current species composition comprises the composition expected in climax (Dyksterhuis 1949). The ecological precept underlying range condition classifications, whether they are based on productivity or species composition, is that vegetation is a product of its environment. This apparent cause-effect relationship between the environment and the vegetation provides the predictability necessary to conduct range inventories and to develop land management plans and monitoring efforts.

Stoddard and Smith (1955), in their classic range management text, stated "no universally accepted basis for vegetation analysis has been developed for the determination of range condition." Dorothy Brown (1954) felt the subject of range condition was in a "formative and controversial stage." Thirty years later, little agreement exists on a methodology for the evaluation of range condition, or for that matter, whether range condition has usefulness in solving today's grazing problems (Anderson and Holte 1981; Bonham 1983; Dyksterhuis 1985; Floyd and Frost 1987; Meeker and Merkel 1984; Smith 1978; Wilson and Tupper 1982).

The reason for part of this professional disparity is that range condition is a concept that integrates many variables. Variables such as forage production, soil surface protection, soil erodability, successional trends, species composition of mixed stands, and canopy coverage effects are so intertwined that univariate measurement and analysis seldom provide a workable basis for evaluation of range condition. In part, the controversy focuses on the ecological philosophies of investigators and the original definition, which related current vegetation back to the historical standard of native vegetation or what is meant by "naturally capable."

This paper discusses some of the conceptual problems associated with the evaluation of range condition as defined by species composition and illustrates a procedure for removing some of the variability in approach while lending flexibility to the method.

THE ECOLOGICAL STATUS AND RESOURCE VALUE RATING CONCEPT

Historically, the condition of the range has been evaluated according to the potential of the site to produce forage or to provide a given species density and composition in climax. There has been a progressive development in the use of ecological stratifications for evaluating range condition ever since the incorporation of climax vegetation as a standard by the Soil Conservation Service in 1935 and the clarification of range condition definitions (Dyksterhuis 1949). Experience has indicated the range condition concept appears less appropriate to forested range where the composition of understory vegetation can be a result of ungulate grazing or tree canopy closure or both (Brown 1954; Dyksterhuis 1985). The concept of ecological potential is also difficult to apply where species normally present at climax are successfully replaced by naturalized non-native vegetation. Examples are Kentucky bluegrass (Poa pratensis L.) replacing tufted hairgrass (Deschampsia caespitosa L.) in a riparian site, or cheatgrass (Bromus tectorum L.) replacing bluebunch wheatgrass (Agropyron spicatum Scribn. & Smith) in an upland grassland community. Here the naturalized vegetation could never rate better than fair condition under the current-to-potential climax concept based on species composition. But the naturalized vegetation could rate higher using the productivity approach if condition is a direct reflection of production.

Over the last several years a concerted effort has been made by the range management profession

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Leonard A. Volland is Regional Plant Ecologist, Pacific Northwest Region, Forest Service, U.S. Department of Agriculture, Portland, OR.

(Society for Range Management 1983) to clarify the range condition concept by proposing the concepts of ecological status and resource value rating.

Ecological status is the relationship of species density and composition to that expected as natural potential in the absence of human-instigated disturbances such as ungulate grazing, excessive recurrent burning, or logging. Ecological status is commonly associated with the stages of community succession as early, mid- and late-seral, and climax.

Resource value rating is the value of the current vegetation with respect to a particular use or benefit. The particular use or benefit is identified (for example, forage for livestock, forage or habitat for wildlife, riparian habitat for fish, recreation for people) and the current vegetation is rated according to what is considered best for the particular resource. The resource value may or may not parallel the successional stages of the ecological status concept. For example, where Kentucky bluegrass has invaded a site previously occupied by a climax dominant like tufted hairgrass, the ecological status may be mid-seral when considering the place bluegrass fits in the seral development to hairgrass under no livestock grazing. However, when bluegrass is evaluated as a forage resource, the stand could rate good to excellent if bluegrass expresses the vigor, composition, and production considered as that species' potential for that site. Another example is the revegetation of a site with crested wheatgrass after the elimination of sagebrush and juniper. Here a non-native species is prescribed so the forage value rating for livestock is improved.

The yardstick for measuring resource value rating can change from one resource to another. Forage value may be based on palatability of vegetation to a particular animal, for example, cattle or sheep, elk or deer. Recreational value may be different for dune buggies compared to value to backpackers or horse users. The relationship of current vegetation to natural potential and resource use becomes more apparent when ecological status is discussed concurrently with resource value (Anderson 1986; Hann 1986).

DEVELOPMENT OF FORAGE RATING GUIDES

Forage rating guides are a resource value rating system that provide numerical and qualitative data on forage as a resource for wild and domestic ungulates. The rating can be based on species density, frequency, composition, production, and/or species presence-absence. Although the guides as described here are primarily used to rate vegetation condition for ungulates as reflected in species composition, the information and concept can also be incorporated into a rating system for watershed protection, wildlife or fish habitat, and foreground visual quality.

The assumption is that any detrimental influence of ungulate grazing is reflected by a decline in the resource value. These ratings are often expressed as classes such as excellent, good, fair, poor, or very poor. The number of classes is determined by the statistical variability in the data as illustrated by Hall (1983). The wider the confidence interval around the mean, the more variable the data and the fewer classes possible. For instance, data collected by using the loop frequency procedure in south-central Oregon indicated forage hits were more variable with respect to their mean, as measured by the coefficient of variation, than was forage composition (table 1). Four forage classes rather than five were used to rate the forage because of the variation expressed between forage guides and between attributes within guides. Forage here is defined as decreasers plus palatable increasers as given in Volland (1985b). Composition was measured using closest perennial methodology with the loop frequency method (Parker and Harris 1959). The mean values are the average of all two-transect clusters sampled for an association as shown under sample size.

Table 1--Statistical data on forage hits and composition by forage guide

Forage Guide	Sample Size	FORAGE HITS			FORAGE COMPOSITION		
		Mean	95% CI	CV	Mean	95% CI	CV
Pine/shrub/ fescue	42	5.5	78	.47	90.2	2.02	.07
Pine/shrub/ needlegrass	55	8	.23	71	87 8	4.24	18
Pine/shrub/ sedge	20	2.7	1.70	1.33	94 5	5.54	.13
Mixed conifer/ pinegrass	13	7.9	3 09	69	78 1	8 94	21

During the classification of plant associations in south-central Oregon, sample stands were selected for their homogeneity in species composition, landform, soils, and relative protection from stand disturbance agents such as recent fires, logging, or grazing. Many of these samples provided the data for good forage rating since they were relatively free from ungulate grazing impacts. Stands in lower ecological status as a result of livestock impacts were sampled in the most commonly occurring meadow, nonforest shrub, and ponderosa pine associations. The data from these grazed samples were regressed in order to adjust the class limits for any forage rating class. Sampling stands in a lower ecological status is necessary unless one wishes to assume a straight line relationship between some species attribute (that is, cover, frequency, or weight) and forage value rating. For example, when palatable species loop frequency was graphed against unpalatable species composition, the Kentucky bluegrass meadow data indicated a decline between good and fair forage rating. The data were too variable to adequately separate stands having these two forage ratings from each other. However, stands of poor forage rating could be separated from fair without difficulty (fig. 1). Forage production data from these stands show even less differentiation due to the cyclic nature of standing crop under rest (Volland 1978) and the decline in palatable biomass with a lower resource value rating.

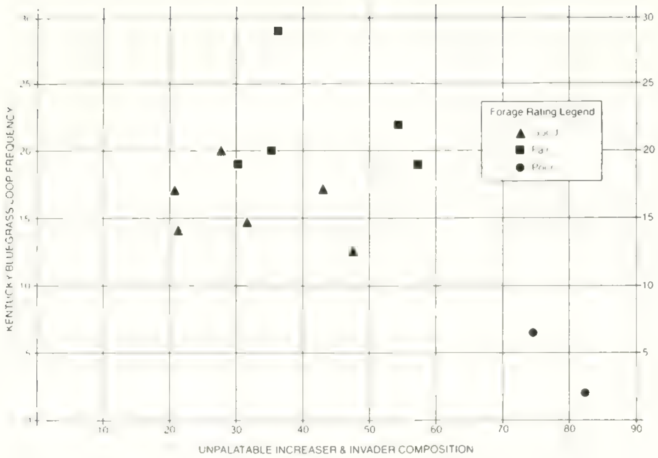

Figure 1--The relationship between Kentucky bluegrass loop frequency and unpalatable species compositions for 13 bluegrass meadows in central Oregon.

FORAGE RATING IN GRAZABLE WOODLAND

In grazable woodland[1], the sampling requirement intensifies in that density and composition of ground vegetation are affected by tree crown closure or tree stocking level as well as historical grazing patterns. As a consequence, forage rating is assessed according to the potential under existing timber stand conditions. The stand condition may be in an ecological status somewhat removed from potential natural community and the climax condition, i.e. pole-sized or immature-aged stands in mid-seral ecological status.

In this study, forage cover and composition data were regressed against tree crown cover or basal area. The forage guides displayed the forage species data by those tree overstory catagories found significant during the analysis (table 2). The top of each forage class reflects the best that can be produced under the prevailing tree overstory situation given minimum grazing impacts. In south-central Oregon about 35-40 percent tree canopy was the point beyond which canopy closure had a significant impact on understory vegetation (fig. 2). This relationship has also been documented by Bartlett and Betters (1983), Hall (1966), and Pyke and Zamora (1982).

The management interpretation of a "poor" forage rating in grazable woodland is that a change in animal management is required to attain an upward trend under the prevailing tree canopy cover found on a particular site. A "good" forage rating implies a change in animal management will probably not result in an upward trend if the prevailing tree canopy is dense enough to impact ground vegetation. This also means that grazable woodlands will have lower species frequency and composition values in stands of dense tree cover than under an open-grown forest stand structure.

Table 2--Forage composition rating guide showing influence of tree canopy and basal area on ground vegetation composition (Volland 1985b)

Forage Guide:	Pine/Shrub/Fescue				Composition Point Rating
Tree cover:	0-35%	36-45%	46-55%	>55%	
Basal area:	0-120 ft²	121-140	141-150	>150 ft²	
Decreaser	81-100	73-90	57-70	41-50	53-65
&	61-80	55-72	43-56	31-40	40-52
palatable:	41-60	35-54	29-42	21-30	27-39
increaser	21-40	19-36	15-28	11-20	14-26
composition	0-20	0-18	0-14	0-10	0-13

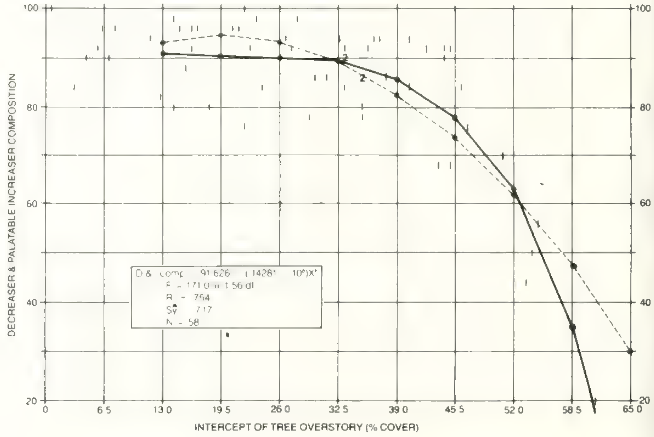

Figure 2--Relationship of decreaser and palatable increaser composition to tree intercept in the Pine/Shrub/Fescue forage group. Inset equation applies to bold face curve.

PLANT ASSOCIATIONS AND FORAGE RATING GUIDES

Plant associations play a key role in the development of forage rating guides. Associations form the basic structure in which vegetation data are collected, analyzed, and eventually disseminated for field use. The species density and composition data are collected and evaluated for significance by plant association. The assumption is made that the ground vegetation information collected from the minimally disturbed stands which represent an association will display little variation across that association. When differences in the data occur, the differences will be due to either differences in tree or shrub canopy closure, geographical differences within an association, or differences between two or more associations.

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[1] Grazable woodland is land on which the natural potential native vegetation is forest. The forest contains understory plants that can be grazed without significantly impairing other forest values. Rangeland is defined as land on which the native or revegetated flora is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing (Society for Range Management 1974).

Initially the data are statistically analyzed for potential differences in species density and composition between associations. The lumping of species into decreaser or palatable increaser categories may mask the differences that occur in species frequency or composition between associations. Whenever nonsignificant differences occur in the data between two associations, the data from each are consolidated to form a new population for a resource value rating. A similar approach has been used by Hall (1971) on data from the Blue Mountains in Oregon to form plant associations and plant community types. As a result of this process, plant associations can be condensed to a smaller number of "resource strata," which are significantly different between themselves in the attributes being analyzed and internally homogeneous in characterization and response to ungulate management. For example, of the 61 plant associations described for the central Oregon pumice zone (Volland 1985a), 33 associations provide available forage for ungulates on a sustained basis. The 33 associations were condensed into 10 significantly different groups, five of which form the rangelands; another five groups form the grazable woodland forage rating guides (see table 3).

The plant association descriptions are used to determine which forage rating guide is appropriate for a site being evaluated. The site is first classified as to which plant association it represents using vegetation-site keys and association descriptions provided by the inital classification effort (Volland 1985a). The appropriate forage guide can then be chosen by finding the computer code associated with the correct association in table 3. Another alternative is to use a vegetation-site key that assists the user in selecting the appropriate forage rating guideline.

Table 3--Forage guides for central Oregon pumice zone with plant association identification codes represented by each guide

Rangeland

1. *Deschampsia caespitosa* (L.) Meadow (MM19)[1]
2. *Poa pratensis* (L.) Meadow (MM90)
3. *Poa cusickii* (Vasey) Meadow (MD19-11)
4. Sagebrush/Bunchgrass (SD19-12, SD29-12, SD29-13)
5. Sagebrush/Needlegrass (SD29-14)

Grazable Woodland

1. Pine/Shrub/Fescue (CPS1-11, CPS2-11, CPS2-16, CPS2-17, CPS3-14, CLS2-14, CLS1-11)
2. Pine/Shrub/Needlegrass (CLS2-13, CLS2-11, CLS2-15, CPS2-12, CPS2-13, CPS3-11, CWS1-14)
3. Pine/Shrub/Sedge (CLS2-12, CPS2-14, CPS2-15, CPS3-12, CWC2-13, CWSI-15, CWS1-13)
4. Pine/Sedge (CLG4-11, CPG2-12, CLG4-12)
5. Mixed Conifer/Pinegrass (CWC2-12, CDS6-14)

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[1] Computer codes given in parentheses identify the specific plant association or community type for which the forage guide applies. Refer to Hall (1984) for a discussion of the computer coding identification process.

ECOLOGICALLY BASED CONDITION RATINGS

There have been some questions raised in the current literature regarding the applicability of ecologically based condition rating systems as a measure for evaluation of management objectives (Floyd and Frost 1987). Kentucky bluegrass, being a naturalized species, was considered as a potential natural community in this study since evidence suggests that Kentucky bluegrass will continue to dominate a meadow site even after an extensive period of complete rest (Volland 1978). Here is an example of a resource value rating being developed on the performance of a palatable increaser that is genetically and physiologically adapted to a livestock grazing regime. A rating system becomes an effective monitoring tool when potential is defined as the optimum achievable condition for a particular resource value within an ecological status that is relative to current or proposed management. The procedure of rating current vegetation to potential vegetation in climax or presettlement conditions becomes less problematic or necessary.

A comprehensive forage rating guide should stratify information by ecological status since imbedded within ecological status are variables that affect the quantitative attributes of forage species: plant association, grazing animal preferences, tree and shrub canopy closure. Consequently, the development of forage rating guides should follow both the classification of vegetation into plant associations and the characterization of seral stages that comprise the association.

INTERPRETATION OF TREND

Trend is a change in vegetation on a specific site in relation to its forage condition rating over time. No apparent trend implies some combination of factors is resulting in a nondetectable change in condition. Downward trend implies improvement in management may be necessary. Upward trend suggests management is probably correct and improvement in forage conditions has occurred.

At the operational level an accurate estimate of trend is influenced by the inherent variability associated with biological systems and the time-budget constraints often placed on monitoring efforts. Consequently, the manager runs the risk of either overstocking or understocking the range if an observation of no apparent trend is not true (the manager commits a Type II statistical error of accepting a false hypothesis of static trend) or if static trend is true but is rejected in favor of an assumed upward or downward trend (the manager commits a Type I statistical error). Tauke and Bonham (1985) discuss in detail the detection of trend from a statistical perspective and show the effect of sample size on the probability of committing Type I or II errors.

The major objective in trend interpretation is to determine the cause of observed trend. The cause of trend should be determined before adjustments in management are made since forage use by livestock is only one of four causes (forage use, associated vegetation, erosion, climatic factors) of observed range trend (Strickler 1968). Consequently, trend evaluation requires repeated vegetation sampling over short time intervals supplemented with measurements of animal, climate, and land treatment impacts on vegetation to discern whether observed change in trend can be affected by livestock management alone.

A forage rating is not necessary for the interpretation of the cause of trend. Assuming forage use by ungulates is the cause for an observed trend, the most a forage rating can do is suggest if an upward trend in current vegetation is feasible. For instance, a good forage rating would imply little or no trend will occur since the site is producing at or near its potential. A fair or poor forage rating implies the site is not producing to its potential and an adjustment in livestock management may improve forage.

SUMMARY

The concepts of forage monitoring and resource value rating have been proposed by the range management profession as being appropriate for addressing resource allocation questions and evaluating progress toward achievement of management objectives. One particular resource value rating, forage rating guidelines, is shown to be closely related to the range condition scorecards developed over the past 40 years. The forage rating guidelines are ecologically based in that plant associations form the basic structure from which species density and composition data are collected, analyzed, and disseminated to field units. Forage rating guidelines are developed for nonforest and forested vegetation, including communities dominated by non-native perennial species. The guidelines incorporate the effects of tree and shrub canopy closure on understory vegetation so that grazing impacts can be separated from the influence of woody vegetation when monitoring the ability of the site to provide forage for domestic and wild ungulates. The evaluation of forage rating for a specific site at different points in time provides an estimate of trend. However, a forage rating is not necessary for the interpretation of what factor(s) caused the observed trend.

REFERENCES

Anderson, E. William. 1986. Rating ecological status and resource values. Rangelands. 8(4): 161-164.

Anderson, Jay E.; Holte, Karl E. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. Journal of Range Management. 34(1): 25-29.

Bartlett, E.T.; Betters, David R. eds. 1983. Overstory-understory relationships in western forests. Western Regional Research Publication No. 1. Fort Collins, CO: Colorado State Experiment Station. 37 p.

Bonham, Charles D. 1983. Range vegetation classification. Rangelands. 5(1): 19-21.

Brown, Dorothy. 1954. Methods of surveying and measuring vegetation. Commonwealth Bureau of Pastures and Field Crops Bulletin 42. Farnham Royal, Bucks, England. (p. 192) 221 p.

Dyksterhuis, E.J. 1985. Follow-up on range sites and condition classes as based on quantitative ecology. Rangelands. 7(4): 172-173.

Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management. 2(3): 104-115.

Floyd, Don; Frost, Bill. 1987. Measuring management objectives with condition classes: time for a change. Rangelands. 9(4): 161-162.

Hall, Frederick C. 1984. Ecoclass coding system for Pacific Northwest plant associations. R6-Ecol 173-1984. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 83 p.

Hall, Frederick C. 1983. Application and interpretation of forest ecosystems classification. In: Roche', Ben; Baumgartner, David. eds. Forestland grazing: Proceedings of the symposium; 1983 February 23-25; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension: 7-14.

Hall, Frederick C. 1971. Some uses and limitations of mathematical analysis in plant ecology and land management. In: Patil, G.P.; Pielou, E.C.; Waters, W.E. eds. Statistical Ecology Vol. 3: Many species populations, ecosystems and systems analysis. University Park, PA: Pennsylvania State University Press: 377-395.

Hall, Frederick C. 1966. Vegetation-soil relations as a basis for resource management on the Ochoco National Forest of central Oregon. Corvillis, OR: Oregon State University. 199 p. Thesis.

Hann, Wendel J. 1986. Evaluation of resource values in the Northern Region of the Forest Service. Rangelands. 8(4): 159-161.

Meeker, D.O.; Merkel, D.L. 1984. Climax theories and a recommendation for vegetation classification--a viewpoint. Journal of Range Management. 37(5): 427-430.

Parker, Kenneth W.; Harris, Robert W. 1959. The 3-step method for measuring condition and trend of forest ranges: a resume of its history, development, and use. In: Techniques and methods of measuring understory vegetation: Proceedings of symposium; 1958 October; Tifton, GA: U.S. Department of Agriculture, Forest Service: 55-69.

Pyke, David A.; Zamora, Benjamin A. 1982. Relationships between overstory structure and understory production in the grand fir/myrtle boxwood habitat type of north central Idaho. Journal of Range Management. 35(6): 769-773.

Smith, E. Lamar. 1978. A critical evaluation of the range condition concept. In: Hyder, Donald N., ed. Proceedings of the First International Rangeland Congress; 1978 August 14-18; Denver, CO. Denver, CO: Society for Range Management: 266-267.

Society for Range Management, Range Inventory Standardization Committee. 1983. Guidelines and terminology for range inventories and monitoring. Denver, CO: Society for Range Management. 13 p.

Society for Range Management. 1974. A glossary of terms used in range management. Denver, CO: Society for Range Management. 36 p.

Stoddard, Laurence A.; Smith, Arthur D. 1955. Range management. 2d ed. New York: McGraw-Hill: 185.

Strickler, Gerald S. 1968. Vegetation response to animal use on the Starkey Experimental Forest and Range. In: Proceedings of range management workshop; 1968 February 5-7; Pullman, WA: Washington State University: 127-139.

Tauke, William C.; Bonham, Charles D. 1985. Use of power curves to monitor range trend. Journal of Range Management. 38(5): 428-431.

Volland, Leonard A. 1978. Trends in standing crop and species composition of a rested Kentucky bluegrass meadow over an 11-year period. In: Hyder, Donald N., ed. Proceedings of the First International Rangeland Congress; 1978 August 14-18; Denver, CO. Denver, CO: Society for Range Management: 526-529.

Volland, Leonard A. 1985a. Plant associations of the central Oregon pumice zone. R6-Ecol-104-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 138 p.

Volland, Leonard A. 1985b. Guidelines for forage resource evaluation within the central Oregon pumice zone. R6-Ecol-177-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 214 p.

Wilson, A.D.; Tupper, G.J. 1982. Concepts and factors applicable to the measurement of range condition. Journal of Range Management. 35(6): 684-689.

WOODLAND CLASSIFICATION: THE PINYON-JUNIPER FORMATION

Barry C. Johnston

ABSTRACT: The climax stands in the Pinyon-Juniper Formation (woodland) can be divided into two subformations: Juniper-Pinyon Woodland, with nine series; and Juniper Steppe Woodland, with two series. Plant associations (habitat types) have been described for most of these series. Challenges of woodland classification include lack of relict stands, properly accounting for codominance without complicating nomenclature, invasion of junipers and pinyons into adjacent ecosystems, and coordination of plant association classification with soils and landform classifications.

EXTENT OF THE FORMATION

Pinyon-juniper stands are common in the western United States, especially in the Great Basin. They comprise part of a group of stands of short trees, often called "woodland." Woodland, as a general term, describes stands of small trees "capable of forming a canopy and hence of constituting a real though low forest" (Clements 1920; also see Daubenmire 1978, Whittaker 1975). The tree canopies are often open and savanna-like, although they can be closed or nearly so.

In its original definition (Clements 1920), "woodland" is a climax classification unit, and so it should have whole climax plant associations nested within it. The Coniferous Woodland Formation (Johnston 1987) consists of climax plant communities dominated by short-stature pine species of _Pinus_ sect. Parrya, subsection Cembroides, all called "pinyons" (Critchfield and Little 1966), and those dominated by several tree juniper species. There are four pinyon species and at least five juniper species that dominate climax stands in the United States (Brown 1982, West 1984, Critchfield and Little 1966). These species are shown in table 1.

Table 1--Species dominating pinyon-juniper stands in the United States

Juniperus californica	
Juniperus deppeana	_Pinus cembroides_
Juniperus monosperma	_Pinus edulis_
Juniperus occidentalis	_Pinus monophylla_
Juniperus osteosperma	_Pinus quadrifolia_
Juniperus scopulorum	

Woodlands have been classified differently since they were first described by Clements; three of these classifications are shown in table 2.

The generalized distribution of all these species (except _Juniperus occidentalis_ and _J. scopulorum_, discussed later) is presented in figure 1 (after Little 1971, Critchfield and Little 1966). When the maps of species were overlaid, there was a large degree of correlation among species. Species within the same genus often had nearly disjunct distributions (for example, _Juniperus monosperma_ and _J. osteosperma_; _Pinus monophylla_ and _P. edulis_). Species in different genera often had a large overlap (for example, _Pinus edulis_ and _Juniperus osteosperma_). Natural species distributional groups that are apparent from figure 1 are shown in table 3.

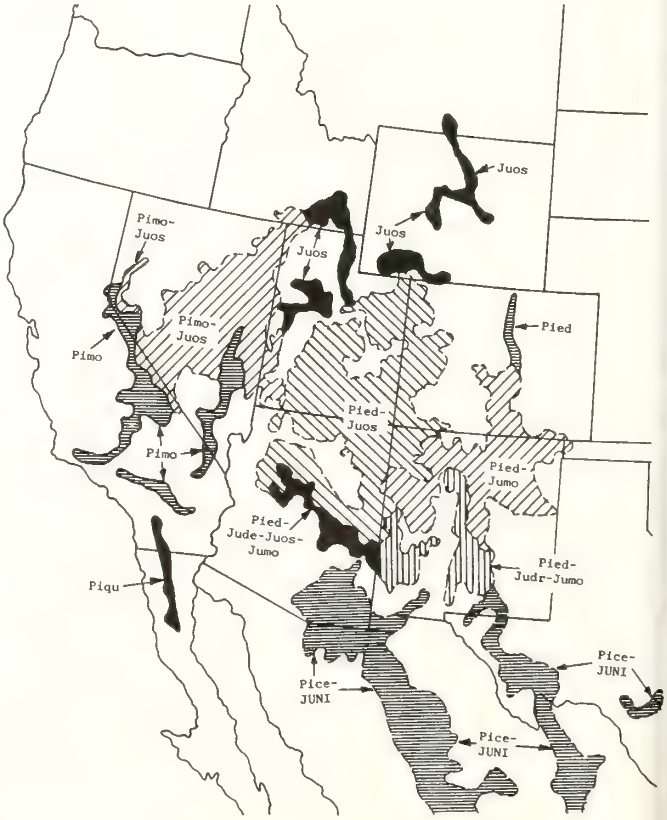

Figure 1--Map of western North America, showing generalized distributions of the leading species within the Coniferous Woodland Formation (after Little 1971, Critchfield and Little 1966)

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Barry C. Johnston is Ecologist, U. S. Department of Agriculture, Forest Service, Rocky Mountain Region, Lakewood, CO.

Table 2--Three different classifications of the woodland climax

Clements 1920	Daubenmire 1978	Johnston 1987
	Temperate Xerophytic Forest Region	
Woodland Climax (Pinyon-Juniper Formation)		Woodland
Pinyon-Cedar Woodland (Pinyon-Juniper Assn.)	*Pinus cembroides* Province	Coniferous Woodland Formation
	1. *Pinus flexilis* Section 2. *Pinus* sect. Cembroides Section	1. Juniper-Pinyon Woodland 2. Juniper Steppe Woodland

The two northern juniper species, *Juniperus occidentalis* and *J. scopulorum*, occur within the range of the pinyons on cooler and higher elevation sites (Brown 1982), but seldom are they leading constituents of these woodlands. However, to the north and elevationally above the distribution of the pinyons, these two junipers dominate stands with other conifers usually not present. These two series, *Juniperus scopulorum* and *J. occidentalis*, merit recognition as a separate subformation, Juniper Steppe Woodland.

CLASSIFICATIONS AT THE HABITAT TYPE LEVEL

Not many plant association (habitat type) or other climax plant community classifications have included pinyon-juniper stands; the usual convention of "forested habitat type" studies is not to sample woodlands. We can therefore expect the classification scheme for woodlands to be incomplete. A partial sample of climax plant associations that have been described appears in table 4.

Table 3--Species groups in the Coniferous Woodland Formation. Within Subformation A, groups are listed as in figure 1

CONIFEROUS WOODLAND FORMATION

A. Juniper-Pinyon Woodland

1. *Juniperus osteosperma* Series

2. *Pinus cembroides-Juniperus* spp. Series

3. *Pinus edulis* Series
4. *Pinus edulis-J. deppeana* Series
5. *Pinus edulis-J. monosperma* Series
6. *Pinus edulis-J. osteosperma* Series

7. *Pinus monophylla* Series
8. *Pinus monophylla-J. osteosperma* Series

9. *Pinus quadrifolia* Series

B. Juniper Steppe Woodland

10. *Juniperus occidentalis* Series

11. *Juniperus scopulorum* Series

Table 4--Plant associations (habitat types) that have been described in the Coniferous Woodland Formation

SUB-FORMATION	PLANT SERIES	PLANT ASSOCIATION	PHASE	REFERENCES
A. Juniper-Pinyon Woodland				
	1. *Juniperus osteosperma* Series			
		Juniperus osteosperma/Roegneria spicata		Ream 1964, Fisser and others 1980
		Juniperus osteosperma/Oryzopsis hymenoides		
	2. *Pinus cembroides-Juniperus* spp. Series			
		Pinus discolor-Quercus emoryi/Arctostaphylos pungens		Moir 1979, Moir and Carleton 1987
		Juniperus erythrocarpa/Bouteloua eriopoda		Moir and Carleton 1987
		Pinus discolor/Cercocarpus brevifolius-Rhus coriophylla		Moir and Carleton 1987
		Pinus discolor/Muhlenbergia emersleyi		Moir and Carleton 1987
		Pinus discolor-Quercus arizonica/Nolina microcarpa		Moir and Carleton 1987
		Pinus discolor/Quercus toumeyi		Moir and Carleton 1987
		Juniperus erythrocarpa/Quercus turbinella		Moir and Carleton 1987
	3. *Pinus edulis* Series			
		Pinus edulis/Andropogon hallii		Moir and Carleton 1987
		Pinus edulis/Artemisia nova		De Velice and others 1986
		Pinus edulis/Cowania mexicana		Baker 1984, Moir and Carleton 1987
		Pinus edulis/Fallugia paradoxa		Moir and Carleton 1987
		Pinus edulis/Festuca arizonica		Merkle 1952, Moir and Carleton 1987

SUB-FORMATION	PLANT SERIES	PLANT ASSOCIATION	PHASE	REFERENCES
	4. Pinus edulis-Juniperus deppeana Series			
		Pinus edulis/Arctostaphylos pungens		Moir and Carleton 1987
		Pinus edulis-Quercus emoryi/Arctostaphylos pungens		Moir and Carleton 1987
		Pinus edulis-Juniperus deppeana/Bouteloua gracilis		Moir and Carleton 1987
		Juniperus deppeana/Bouteloua gracilis		Moir and Carleton 1987
		Pinus edulis-Juniperus deppeana/Bouteloua gracilis		Kennedy 1983, Moir and Carleton 1987
		Pinus edulis-Juniperus deppeana/Cercocarpus montanus		Moir and Carleton 1987
		Juniperus deppeana-J. monosperma/Cercocarpus montanus-Ceanothus greggii		Moir and Carleton 1987
		Pinus edulis-Juniperus deppeana/Muhlenbergia dubia		Kennedy 1983, Moir and Carleton 1987
		Juniperus deppeana/Muhlenbergia emersleyi		Moir and Carleton 1987
		Juniperus deppeana/Panicum obtusum		Moir and Carleton 1987
		Pinus edulis/Quercus turbinella		Moir and Carleton 1987
		Juniperus deppeana-Quercus grisea/Rhus aromatica ssp. trilobata		Moir and Carleton 1987
		Pinus edulis-Quercus emoryi/Rhus aromatica ssp. trilobata		Moir and Carleton 1987
	5. Pinus edulis-Juniperus monosperma Series			
		Juniperus monosperma/Agave lechuguilla		Moir and Carleton 1987
		Juniperus monosperma/Andropogon hallii		Moir and Carleton 1987
		Pinus edulis-Juniperus monosperma/Bouteloua curtipendula		Baker 1984
		Pinus edulis-Juniperus monosperma/Bouteloua gracilis		Jameson 1966, Wright and others 1973, Shepherd 1975, Brown 1982, Kennedy 1983, Francis 1986, Moir and Carleton 1987
		Juniperus monosperma/Bouteloua gracilis		Wright and others 1973, Francis 1986
			Phase Quercus turbinella	Moir and Carleton 1987
		Pinus edulis-Juniperus monosperma/Cercocarpus montanus		Kennedy 1983, Moir and Carleton 1987
			Phase Ribes cereum	Baker 1984
		Juniperus monosperma/Elytrigia smithii		Arnold 1964, Francis 1986
		Juniperus monosperma/Fallugia paradoxa		Moir and Carleton 1987
		Juniperus monosperma/Larrea divaricata		Moir and Carleton 1987
		Pinus edulis-Juniperus monosperma/Muhlenbergia pauciflora		Kennedy 1983, Moir and Carleton 1987
		Juniperus monosperma/Muhlenbergia pungens		Moir and Carleton 1987
		Juniperus monosperma/Nolina microcarpa		Moir and Carleton 1987
		Juniperus monosperma/Quercus undulata		Moir and Carleton 1987
		Pinus edulis-Juniperus monosperma/Stipa nelsonii		Kennedy 1983, Moir and Carleton 1987
		Juniperus monosperma-Pinus edulis/Stipa neomexicana		Baker 1984
		Juniperus monosperma-Pinus edulis/Stipa scribneri		Baker 1984
	6. Pinus edulis-Juniperus osteosperma Series			
		Pinus edulis-Juniperus osteosperma/Amelanchier utahensis-Cercocarpus montanus		Hess and Wasser 1982, Baker 1983, Madany and West 1984
			Phase Arctstaphylos patula	Baker 1983, Madany and West 1984
			Phase Carex pityophila	Baker 1984
			Phase Roegneria spicata	Baker 1982
		J. osteosperma-Pinus edulis/Artemisia nova		Baker 1984
			Phase Roegneria spicata	Baker 1984
		Pinus edulis-Juniperus osteosperma/Artemisia tridentata		Rasmussen 1941, Tiedeman 1978, Brotherson and others 1983, Moir and Carleton 1987
			Phase Bouteloua gracilis	Brotherson and others 1983
		Pinus edulis-Juniperus osteosperma/Bouteloua gracilis		Moir and Carleton 1987
		J. osteosperma-Pinus edulis/Cercocarpus ledifolius		Baker 1984
		Pinus edulis-J. osteosperma/Cercocarpus montanus		Erdman 1970, Greenwood and Brotherson 1978, Moir and Carleton 1987
			Phase Elymus salinae	Baker 1984
			Phase Roegneria spicata	Baker 1984
			Phase Quercus gambelii	Moir and Carleton 1987
			Phase Quercus undulata	Moir and Carleton 1987
		Juniperus osteosperma/Cercocarpus montanus-Peraphyllum ramosissimum		Hess and Wasser 1982, Baker 1983
		J. osteosperma-Pinus edulis/Cowania mexicana		Brown 1982, Baker 1984
		Juniperus osteosperma/Elymus salinae		Baker 1982
		J. osteosperma-Pinus edulis/Hilaria jamesii		Baker 1984

SUB-FORMATION	PLANT SERIES	PLANT ASSOCIATION	PHASE	REFERENCES
		Juniperus osteosperma/Hilaria mutica		Moir and Carleton 1987
			Phase Artemisia tridentata	
		Pinus edulis-Juniperus osteosperma/Mahonia fremontii		Mason and others 1967, Komarkova 1986
		Pinus edulis/Muhlenbergia pungens		Moir and Carleton 1987
		J. osteosperma-Pinus edulis/Oryzopsis hymenoides		Baker 1984
		Pinus edulis-Juniperus osteosperma/Poa fendleriana		Erdman and others 1969, Baker 1982-4, Moir and Carleton 1987
		Pinus edulis-Juniperus osteosperma/Purshia tridentata		Erdman and others 1969, Austin and others 1984, Baker 1984, Moir and Carleton 1987
		Pinus edulis-Juniperus osteosperma/Quercus gambelii		Merkle 1952, Mason and others 1967, Steinhoff 1978, Hess and Wasser 1982, Baker 1984, Moir and Carleton 1987
		Juniperus osteosperma-Pinus edulis/Roegneria spicata		Harniss and West 1973, Fisser and others 1979, Baker 1983
		Juniperus osteosperma/Stipa neomexicana		Moir and Carleton 1987
	7. Pinus monophylla Series			
	8. Pinus monophylla-Juniperus osteosperma Series			
		Pinus monophylla-J. osteosperma/Amelanchier pallida		Young and others 1976
		Pinus monophylla-J. osteosperma/Artemisia nova		Beatley 1979, Everett and others 1983
		Pinus monophylla-J.osteosperma/Cercocarpus ledifolius		Young and others 1976
		Pinus monophylla-J. osteosperma/Cowania stansburyiana		Young and others 1976
		Pinus monophylla-J. osteosperma/Festuca idahoensis		Everett and Sharrow 1985
		Pinus monophylla-J. osteosperma/Purshia tridentata		Young and others 1976
			Phase Festuca idahoensis	Everett and others 1983
		Pinus monophylla/Quercus turbinella		Moir and Carleton 1987
		Pinus monophylla/Quercus turbinella-Arctostaphylos pungens		Moir and Carleton 1987
			Phase Quercus emoryi	Moir and Carleton 1987
	9. Pinus quadrifolia Series			
		Pinus quadrifolia-Juniperus californica		Brown 1982
B. Juniper Steppe Woodland				
	10. Juniperus occidentalis Series			
	11. Juniperus scopulorum Series			
		Juniperus scopulorum/Artemisia tridentata		Hess 1981, Baker 1984, Hess and Alexander 1986
		Juniperus scopulorum/Cercocarpus montanus		Hess 1981, Baker 1984, Hess and Alexander 1986
		Juniperus scopulorum/Muhlenbergia filiculmis		Baker 1984
		Juniperus scopulorum/Oryzopsis micrantha		Nelson 1961, Hansen 1984, Girard 1985, Hansen and Hoffman 1986
		Juniperus scopulorum/Purshia tridentata		Hess 1981, Baker 1984, Hess and Alexander 1986
		Juniperus scopulorum/Quercus gambelii		Baker 1984
		Juniperus scopulorum/Roegneria spicata		Brown 1971, Terwilliger and Tiedeman 1978, Baker 1984, Hansen and Hoffman 1986, Tiedeman and others 1987
		Juniperus scopulorum/Schizachyrium scoparium		Baker 1984

CHALLENGES IN CLASSIFICATION

A mixture of tree species is common to most stands, especially within the Juniper-Pinyon Woodland. Codominance is the rule in woodlands, rather than the exception. This causes some difficulties in nomenclature, challenging us to maintain distinctions among plant associations on really different sites, while at the same time using an uncomplicated nomenclature, and grouping associations into series based on their close relationships.

Even though the distinctions among tree species are fairly sharp, as shown above, it is not difficult to find stands with similar environments and understory species, that range from nearly complete pinyon dominance to nearly complete juniper dominance. Multiple species names as series names seems inevitable; for example, a series comprising all the plant associations with Pinus edulis dominant would be highly artificial and too broad.

At the same time, stands dominated by juniper may in some cases be closely related to stands dominated by pinyon. Separating them into separate series may be just as artificial.

In many places, junipers and pinyons have invaded adjacent shrubland or grassland in historical times. This has been especially dramatic with Juniperus occidentalis. The classification must cover all types within the study area, and be correlated with soils and landform, and the key must include abiotic as well as biotic characters, so that these invasions can be detected.

One of the most important uses of a climax classification system is shown by the considerable utility of habitat types to provide the most significant stratification of the land surface (Daubenmire 1952). This stratification apparently is applicable to juniper-pinyon woodlands, just as it is to every other formation, but is often hampered by the difficulty of finding stands at or near climax.

Many of these stands have been intensively grazed by livestock, which has had widespread effects. The sites are often sensitive to grazing use, and apparently recover slowly or not at all. This situation can make it difficult to find relict stands, and make stands difficult to identify to climax type. In some areas, there may be only 3 to 5 percent of the acres of a habitat type that are recognizable as to type on vegetation criteria (Baker 1982). From a classification point of view, it becomes critical to correctly assess the past history of a stand.

At the same time, many juniper-pinyon habitat types are correlated with soils, landform, or geology, and more use needs to be made of these criteria when delineating plant associations and writing keys. The greatest progress is being made in situations where site characters are used to describe species and association distribution. This is remarkably appropriate for a science whose roots is in the indicator plant concept of Clements (1920).

REFERENCES

Arnold, J. F. 1964. Zonation of understory vegetation around a juniper tree. Journal of Range Management. 17(1):41-42.

Baker, W. L. 1982. Inventory of the Piceance Basin, Colorado. Appendix D: Natural vegetation of the Piceance Basin. Report to U. S. Department of the Interior, Bureau of Land Management, Craig, CO. Denver, CO: The Nature Conservancy. 113 p.

Baker, W. L. 1983. Some aspects of the presettlement vegetation of the Piceance Basin, Colorado. Great Basin Naturalist. 43(4): 687-699.

Baker, W. L. 1984. A preliminary classification of the natural vegetation of Colorado. Great Basin Naturalist. 44(4):647-676.

Beatley, J. C. 1979. Fluctuations and stability in climax shrub and woodland vegetation of the Mojave, Great Basin, and transition deserts of southern Nevada. Israel Journal of Botany. 28:149-168.

Brotherson, J. D.; Rushforth, S. R.; Johansen, J. R. 1983. Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Arizona. Journal of Range Management. 36(5):579-581.

Brown, D. E. 1982. Great Basin conifer woodland (122.4). In: D. E. Brown, ed. Biotic Communities of the American Southwest--United States and Mexico. Desert Plants. 4(1-4): 1-341.

Brown, R. W. 1971. Distribution of plant communities in southeastern Montana badlands. American Midland Naturalist. 85(2):458-477.

Clements, F. E. 1920. Plant indicators: the relation of plant communities to process and practice. Carnegie Institute of Washington Publication 290. 388 p.

Critchfield, W. B.; Little, E. L., Jr. 1966. Geographic distribution of the pines of the world. Miscellaneous Publication 991. Washington, DC: U. S. Department of Agriculture, Forest Service. 97 p.

Daubenmire, R. F. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Daubenmire, R. 1978. Plant geography, with special reference to North America. Academic, New York: 338 p.

DeVelice, R. L.; Ludwig, J. A.; Moir, W. H.; Ronco, F., Jr. 1986. A classification of forest habitat types of northern New Mexico and southern Colorado. General Technical Report RM-131. Fort Collins, CO: Rocky Mountair Forest and Range Experiment Station. 59 p.

Emerson, F. W. 1932. The tension zone between the grama grass and pinyon-juniper associations in northeastern New Mexico. Ecology. 13(4):347-358.

Erdman, J. A. 1970. Pinyon-juniper succession after natural fires on residual soils of Mesa Verde, Colorado. Brigham Young University Science Bulletin, Biological Series. 11(2): 1-26.

Erdman, J. A.; Douglas, C. L.; Marr, J. W. 1969. Wetherill Mesa studies: environment of Mesa Verde, Colorado. Archeological Research Series Number 7-B. Washington, DC: U. S. Department of the Interior, National Park Service. 72 p.

Everett, R. L., compiler. 1987. Proceedings--pinyon-juniper conference. General Technical Report INT-215. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 581 p.

Everett, R. L; Sharrow, S. H. 1985. Soil water and temperature in harvested and non-harvested pinyon-juniper stands. Research Paper INT-342. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 5 p.

Everett, R. L.; Sharrow, S. H.; Meeuwig, R. O. 1983. Pinyon-juniper woodland understory distribution patterns and species associations. Bulletin of the Torrey Botanical Club. 110(4): 454-463.

Fisser, H. G.; Owens, M. K.; Uhlich, J. W.; Waugh, W. J.; Rodgers, D. R.; Hargis, N. E. 1980. Phenology and production studies on semi-arid shrub types, Volume 2: Precipitation, productivity, and production section. Scientific Report 1106. Laramie, WY: Wyoming Agricultural Experiment Station. University of Wyoming. 216 p.

Francis, R. E. 1986. Phyto-edaphic communities of the upper Rio Puerco watershed, New Mexico. Research Paper RM-272. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 73 p.

Girard, M. M. 1985. The ecology and habitat type classification of native woodlands of southwestern North Dakota. Fargo, ND: North Dakota State University. Thesis.

Greenwood, L. R.; Brotherson, J. D. 1978. Ecological relationships between pinyon-juniper and true mountain mahogany stands in the Uintah Basin, Utah. Journal of Range Management. 31(3):164-167.

Hansen, P. L.; Hoffman, G. R. 1986. The vegetation of the Grand River/Cedar River, Sioux, and Ashland Divisions of the Custer National Forest: A habitat type classification. Brookings, SD: South Dakota State University. 255 p. Thesis.

Hansen, P. L.; Hoffman, G. R.; Bjugstad, A. J. 1984. The vegetation of Theodore Roosevelt National Park, North Dakota: a habitat type classification. General Technical Report RM-113. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 35 p.

Hess, K. 1981. Phyto-edaphic study of habitat types of the Arapaho-Roosevelt National Forest, Colorado. Fort Collins, CO: Colorado State University. 558 p. Dissertation.

Hess, K.; Alexander, R. R. 1986. Forest vegetation of the Arapaho and Roosevelt National Forests in central Colorado: a habitat type classification. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 46 p.

Hess, K.; Wasser, C. H. 1982. Grassland, shrubland, and forestland habitat types of the White River-Arapaho National Forest. Final Report, Cooperative Agreement. Lakewood, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Region. 335 p.

Jameson, D. A. 1966. Pinyon-juniper litter reduces growth of blue grama. Journal of Range Management. 19(4):214-217.

Johnston, B. C. 1987. Plant associations of region two: potential plant communities of Wyoming, South Dakota, Nebraska, Colorado, and Kansas. R2-ECOL-87-2. Lakewood, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Region. 429 pp.

Kennedy, K. L. 1983. A habitat type classification of the pinyon-juniper woodlands of the Lincoln National Forest, New Mexico. In: W. H. Moir and L. Hendzel, coordinators. Proceedings of the workshop on southwestern habitat types. April 6-8, 1983; Albuquerque, NM. Albuquerque, NM: U. S. Department of Agriculture, Forest Service, Southwestern Region: 54-61.

Komarkova, V. 1986. Habitat types on selected parts of the Gunnison and Uncompahgre National Forests. Final Report to Rocky Mountain Forest and Range Experiment Station. Boulder, CO: University of Colorado, Institute of Arctic and Alpine Research. 270 p. + appendices.

Little, E. L., Jr. 1971. Atlas of United States trees, volume 1: conifers and important hardwoods. Miscellaneous Publication 1146. Washington, DC: U. S. Department of Agriculture, Forest Service. 319 p. (unnumbered).

Madany, M. H.; West, N. E. 1984. Vegetation of two relict mesas in Zion National Park. Journal of Range Management. 37(5):456-461.

Mason, L. R.; Andrews, H. M.; Carley, J. A.; Haacke, E. D. 1967. Vegetation and soils of No Man's Land Mesa relict area, Utah. Journal of Range Management. 20(1):45-49.

Merkle, J. 1952. An analysis of a pinyon-juniper community at Grand Canyon, Arizona. Ecology. 33(3):375-384.

Moir, W. H. 1979. Soil-vegetation patterns in the central Peloncillo Mountains, New Mexico. American Midland Naturalist. 102(2):317-331.

Moir, W. H.; Carleton, J. O. 1987. Classification of pinyon-juniper (P-J) sites on National Forests in the southwest. In: R. L. Everett, compiler. Proceedings--pinyon-juniper conference. General Technical Report INT-215. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 216-226

Nelson, J. L. 1961. Composition and structure of the principal woody vegetation types in the North Dakota badlands. Fargo, ND: North Dakota State University. 195 p. Thesis.

Rasmussen, D. I. 1941. Biotic communities of Kaibab Plateau, Arizona. Ecological Monographs. 3:229-275.

Ream, R. R. 1964. The vegetation of the Wasatch Plateau, Utah and Idaho. Madison, WI: University of Wisconsin. 134 p. Thesis.

Shepherd, H. R. 1975. Vegetation of two dissimilar bighorn sheep ranges in Colorado. Division Report 4. Denver, CO: Colorado Divsion of Wildlife. 233 p.

Steinhoff, H. W. 1978. Management of Gambel oak associations for wildlife and livestock. Lakewood, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Region. 119 p.

Terwilliger, C., Jr.; Tiedeman, J. A. 1978. Habitat types of the mule deer critical winter range and adjacent steppe region of Middle Park, Colorado. Final Report to U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 108 p.

Tiedeman, J. A. 1978. Phyto-edaphic classification of the Piceance Basin. Fort Collins, CO: Colorado State University. 281 p. Dissertation.

Tiedeman, J. A.; Francis, R. E.; Terwilliger, C., Jr.; Carpenter, L. H. 1987. Shrub-steppe habitat types of Middle Park, Colorado. Research Paper RM-273. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p.

West, N. E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. In: National Research Council, National Academy of Sciences. Developing Strategies for Rangeland Management. Boulder, CO: Westview Press: 1301-1332.

Whittaker, R. H. 1975. Communities and ecosystems, second edition. New York: Macmillan. 385 p.

Wright, H. E., Jr.; Bent, A. M.; Hansen, B.S.; Maher, L. J., Jr. 1973. Present and past vegetation of the Chuska Mountains, northwestern New Mexico. Geological Society of America Bulletin. 84:1155-1180.

Young, J. A.; Evans, R. A.; Tueller, P. T. 1976. Great Basin plant communities--pristine and grazed. In: R. Elston, ed. Holocene environmental change in the Great Basin. Nevada Archeological Survey Research Paper No. 6: 186-215.

SHRUB-STEPPE CLASSIFICATION IN THE WESTERN UNITED STATES

Edwin W. Tisdale

ABSTRACT: Classification of shrub-steppe ecosystems has progressed greatly as the result of studies during the past three decades. Currently, classification on the habitat type model has been developed for much of the region, and the recognition of range (ecological) sites within habitat types has increased the value of the system for management. The major need for future study is a better understanding and classification of seral vegetation in the type.

INTRODUCTION

The term shrub-steppe is a purely descriptive one, denoting a group of natural communities in which a shrub layer is associated with one or more herbaceous layers, usually dominated by perennial grasses. This broad category includes several communities of major importance in the wildlands of the Intermountain and Northwestern regions of the United States and adjacent areas in southwestern Canada.

The most extensive type is the sagebrush-steppe, with a shrub layer dominated by woody species of sagebrush (Artemisia), and occupying some 143 M acres (58 M ha) (Branson and others 1967). The other major type is the shadscale or salt-desert shrub, with an estimated area of 38 M acres (17 M ha) and a shrub layer dominated by species of Atriplex and other members of the goosefoot (Chenopodiaceae) family. Only a portion of this type can be confidently designated as shrub-steppe, with significant herbaceous layers. Other communities consist of nearly pure stands of one or more of the shrubby Chenopods, and the prior existence of an herbaceous layer in these cases is a matter of conjecture.

Smaller communities of shrub-steppe are dominated by species of rabbit brush (Chrysothamnus), wild buckwheat (Eriogonum), snowberry (Symphoricarpos), antelope bitterbrush (Purshia tridentata), mountain mahogany (Cercocarpus), and others. I know of no reliable estimate for the area occupied by such types, but they are sizable and important in many localities.

Shrub-steppe communities collectively represent a major wildland resource in the area under discussion. Historically, their major value has been perceived as a grazing resource for domestic livestock and as habitat for a variety of wildlife. More recently, the watershed influences and recreational values of these lands have also come to be appreciated (Blaisdell and others 1982).

CLASSIFICATION-CONSTRAINTS

Early classifications of shrub-steppe types were so broad as to be almost meaningless. In the early 1950s, Billings (1951) noted the lack of basic synecological knowledge for these communities. Great progress has been made since this time, but much remains to be done. To understand the slow development and currently incomplete state of classification, one must consider certain factors that have slowed the progress of ecological understanding. I will use sagebrush vegetation as a prime example of this situation, but most of my remarks apply equally to other shrub-steppe communities.

The most important inhibiting factor for ecological study has been the severe and widespread disturbance resulting from grazing by domestic livestock. Grazing pressure prior to white settlement appears to have been relatively light (Butler 1976) and the native forage species were not well adapted for the concentrations of domestic livestock that appeared in the 1800's. The result was a marked decline in native grasses and other palatable species, and their replacement by more grazing-tolerant species. The extent of range deterioration was sufficient to arouse official concern by the turn of the century (Kennedy and Doten 1901; Griffith 1902), but several more decades passed before serious efforts were made to control grazing use. By this time, much of the vegetation had come to consist of dense stands of sagebrush, with a sparse herbaceous understory consisting mainly of introduced annuals such as cheatgrass (Bromus tectorum). The main exception to this type of cover was in areas where fire had killed most of the sagebrush and produced an annual grassland type.

These changes in vegetation contributed strongly to a perception of the sagebrush type as a form of desert. This concept is evident in the description and illustration of the type by Shantz and Zon (1924), which depicts a thoroughly depleted stand with abundant sagebrush and a

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Edwin W. Tisdale is Professor Emeritus, Department of Range Resources, University of Idaho, Moscow, ID.

sparse understory of exotic annuals. Their designation of the type as "sagebrush desert" or "northern desert shrub" became widely accepted and is perpetuated by the equally inappropriate term "cold desert."

This view of the sagebrush-steppe as a uniform desert type, coupled with the scarcity of relatively undisturbed stands, combined to discourage serious ecological investigation at a time when many other wildland communities were being studied in some detail.

A second factor inhibiting ecological understanding of the sagebrush-steppe was the great geographical extent and ecological variation of the type. Geographically it extends from southwestern Canada south nearly to the Mexican border, and from points close to the Pacific coast east to western North and South Dakota. The type occurs at elevations ranging from near sea level to 10,000 feet (3,050 m) or more, with annual precipitation from 6 to 30 inches (150-750 mm) and comparable differences in temperature regimes. Differences in vegetation are equally great, as shown by many recent studies (Hironaka 1979).

A third factor affecting progress has been the scarcity of taxa that are sufficiently narrow in ecological amplitude to serve as reliable indicators of specific ecosystems. The principal grasses of the herbaceous layer, such as bluebunch wheatgrass (Agropyron spicatum), Idaho fescue (Festuca idahoensis), and Sandberg bluegrass (Poa secunda) exhibit strong ecotypic variation (Tisdale and Hironaka 1981), but lack corresponding morphological differences that can separate populations in the field. Some of the associated forbs are fairly restricted in distribution, but often their frequency of occurrence is too low and/or irregular to have indicator value.

The best indicator species have proved to be the many kinds of sagebrush occurring in the region. The taxonomic section (Tridentatae) of Artemisia, which includes the woody species, is described as "a complex in a dynamic state of expansive evolution and hybridization" (Shultz 1984). Investigations during the past 35 years, including those of Ward (1953), Beetle (1960), Beetle and Young (1965), Winward (1970, 1980), and Goodrich and others (1985), have clarified relationships and revealed the presence of a number of previously unrecognized taxa within this complex. Fortunately for ecologists and land managers, these taxa have proven to be ecological as well as taxonomic entities, with each one adapted to a special set of conditions within the sagebrush ecosystem. The result has been the development of a number of stable communities, each dominated by a single taxon of sagebrush and differing in its herbaceous vegetation. At least 14 recognized kinds of sagebrush now fill this role of dominants, and given the variability within the group, it is likely that additional taxa will be recognized in the future.

CLASSIFICATION--PROGRESS AND CURRENT STATE

Serious attempts at classification of the sagebrush-steppe date from the mid-1950's. They involved detailed study of relatively undisturbed stands, along with investigation of the physical and biotic factors affecting them (Poulton and Tisdale 1961). Much of the early work was supported by Hatch Regional Project W-25, which provided funds for community studies within Oregon, Washington, and Idaho and for the taxonomic studies of Beetle (1960). The habitat type and series concepts, developed first for forest vegetation (Daubenmire 1952), proved applicable to sagebrush and other shrub-steppe vegetation and have been applied widely.

Significant progress in classification of sagebrush-steppe vegetation has been made in Washington (Daubenmire 1970), Oregon (Eckert 1958; Tueller 1962), Idaho (Hironaka and others 1983; Schlatterer 1972; Tisdale and others 1965), Montana (Mueggler and Stewart 1980), Wyoming (Brodahl 1977), Nevada (Jensen and Peck 1986; Zamora and Tueller 1977), and Colorado (Francis 1983). Hugie and others (1974) have also described sagebrush communities in Idaho, Utah, and Nevada. Several sagebrush habitat types have been recognized in southern British Columbia (McLean 1970).

In the application of this system to the sagebrush-steppe, each Artemisia taxon forms a series, and each series contains one to several habitat types, which differ in the composition of their herbaceous layers. For example, in Idaho, basin big sagebrush (Artemisia tridentata ssp. tridentata) is the dominant shrub for a series that includes four recognized habitat types, with the herbaceous layer dominated by bluebunch wheatgrass, needle-and-thread (Stipa comata), Idaho fescue, and Basin wild rye (Elymus cinereus), respectively. These communities all occur on relatively dry sites with deep, well drained soils, but differ in other site characteristics such as soil texture, topography, and so on. The fact that subspecies as well as species of sagebrush form distinct series attests to the ecological differences among these taxa.

Most of these communities are regional in distribution. Three of the four big sagebrush habitat types listed above have also been recognized in Oregon, Washington, British Columbia, Nevada, and Montana. Similarly, low sagebrush (Artemisia arbuscula ssp. arbuscula), forms habitat types with bluebunch wheatgrass and Idaho fescue in Idaho and most of the states listed above. Habitat types of the same name in widely separated areas are readily recognizable in the field and possess many vegetational and site characteristics in common.

Sagebrush habitat types also exhibit a large amount of internal variability. This is often evidenced more in productivity of the vegetation than in botanical composition, and is related to variations in site characteristics. Such differences in vegetation and site provide the basis for further stratification into range or ecological sites. These finer divisions form the basis for management in many areas, and where recognized as subdivisions of known habitat types, they can provide good measures of ecosystem potential. Currently range sites described in the tri-state area of Idaho, Oregon, and Washington are related to habitat types, as shown in table 1.

As indicated in table 1, Wyoming big sagebrush (A. tridentata ssp. wyomingensis) forms a series in which Wyoming big sagebrush/bluebunch wheatgrass

Table 1--Sagebrush-steppe vegetation in southern Idaho classified to series, habitat type, and range site levels

Series Dominant Artemisia tridentata	Habitat type	Production lb/acre	Range Site
ssp. wyomingensis	ARTRW/AGSP	450	B11-4-1 Shallow Loamy
ssp. wyomingensis	ARTRW/AGSP	600	B11-5-1 Stony
ssp. wyomingensis	ARTRW/AGSP	400	B11-8-1 South Slope
ssp. wyomingensis	ARTRW/AGSP	750	B11-1-1 Loamy
ssp. vaseyana	ARTRV/Feid	1,200	D25-22-1 Loamy
ssp. vaseyana	ARTRV/Feid	1,800	D25-23-1 North Slope

is a common type. Four range sites, distinguished by differences in productivity, soil, and topographic characteristics have been recognized, and further study may reveal more. All occur within areas of low precipitation (250-300 mm) with relatively shallow, and/or rocky soils. A similar situation occurs with a more mesic subspecies, mountain big sagebrush (A. tridentata vaseyana) where mountain big sagebrush/Idaho fescue constitutes a widely distributed and productive association that contains at least two range sites.

A major problem currently limiting broad application of vegetational classification is scarcity of information regarding seral vegetation in the sagebrush-steppe type. The effort required to study undisturbed sites has usually not been extended to the successional stages within these types yet most sagebrush vegetation is in some seral stage. Evaluation of the potential of depleted stands requires the ability to place them within their correct habitat type, and even range site. This should be possible based on the combined use of vegetational and site factors.

In the case of the vegetation, much more information is needed concerning the successional stages that develop from disturbance within each habitat type. Huschle and Hironaka (1980) have proposed a cone model that relates the several seral communities produced by disturbance to the climax community. Preliminary studies (Hann 1982) indicate the possibilities of this approach, but its application to shrub-steppe vegetation needs to be tested. One constraint for study of seral stands of sagebrush-steppe is the slow rate of succession, even after the apparent disturbing factors are removed or greatly modified. Lack of a seed source for the climax herbaceous species, the inertia produced by dominance of an existing stand by long-lived shrubs, and selective grazing of sparse stands of palatable herbaceous species by native rodents and rabbits appear to be the principal factors responsible for this phenomenon.

Another factor affecting some seral stands is the great masking of community differences by the widespread dominance of introduced species such as cheatgrass. Fortunately, another characteristic of sagebrush communities can be helpful in the study of seral stands. Since most sagebrush species are low in palatability to livestock, the shrub layer usually remains on depleted areas, and can provide identification of the type to series level. This grouping gives a measure of site potential. Although this is not as valuable as identification to habitat type or range site, it is useful for many purposes, including evaluation for sagebrush control and range revegetation (Johnson 1987).

Alternatively, depleted stands may also be classified based on their site characteristics, especially soils. Since both vegetation and soils are products of the ecosystem, the relationship between their classification units should be strong. In practice, the correlation between soils and vegetation has frequently been found to be rather weak (Daubenmire 1970; Hugie and others 1974; Jensen and Peck 1986). Much of this lack of correlation may be due to the imperfect state of vegetation and soil classification in shrub-steppe types; this situation should improve with further study. Another promising approach used successfully in grasslands (Tisdale and Bramble-Brodahl 1983) is available through analysis of the combined effects of a group of site factors, which can be measured by techniques such as discriminant analysis. An example of this is reported by Jensen and Peck (1986) for sagebrush-steppe vegetation in northern Nevada. The authors found strong relationships between plant communities and a group of soil characteristics that included profile depth, subsoil clay content, and total rock content.

CONCLUSIONS

Appraisal of the current status suggests that classification of shrub-steppe vegetation by the habitat type or association approach is a useful tool in resource appraisal and management. Data on the associated soil and other site characteristics are an essential part of this ecosystem classification, particularly where so much of the vegetation is in seral stages.

The development of workable classifications in the shrub-steppe has proved to be directly dependent on the ecological (and taxonomic) data available, and thus on the quantity and quality of supportive research. Meaningful classification has come as a logical outgrowth from basic understanding of the vegetation. Skills for application of these systems in the field must also be considered. Accurate identification of plant species is essential, and in some cases, such as the subspecies of big sagebrush, requires considerable training and experience. Similarly, some of the soil differences among sagebrush communities are not readily apparent without considerable knowledge.

Future needs include extension of classification into geographical areas and communities where it has not been actively pursued, and refinement of existing schemes in the light of increased knowledge. The biggest challenge, however, is that of developing a better understanding and a workable classification of ecosystems supporting seral vegetation.

REFERENCES

Beetle, A. A. 1960. A study of sagebrush, the section Tridentatae of Artemisia. Bull. 368. Laramie, WY: University of Wyoming, Agricultural Experiment Station. 83 p.

Beetle, A. A.; Young, A. 1965. A third subspecies in the Artemisia tridentata complex. Rhodora. 67: 405-406.

Blaisdell, James P.; Murray, Robert B.; McArthur, E. Durant. 1982. Managing Intermountain rangelands: sagebrush-grass ranges. Gen. Tech. Rep. INT-134. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 41 p.

Billings, W. D. 1951. Vegetational zonation in the Great Basin of Western North America. Union of International Scientitists. Biological Series B. No. 9: 101-122.

Branson, F. A; Miller, R. F.; McQueen, I. S. 1967. Geographical distribution and factors affecting the distribution of salt-desert shrubs in the United States. Journal of Range Management. 20: 287-296.

Brodahl, Mary K. 1977. Classification of sagebrush vegetation in the Gros Ventre area, Wyoming. Moscow, ID: University of Idaho. 126 p. Thesis.

Butler, B. R. 1976. The evolution of the modern sagebrush-grass steppe on the eastern Snake River Plain. In: Holocene environmental change in the Great Basin. Nevada Archaeological Society, Research Paper No. 6: 5-39.

Daubenmire, R. F. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22: 301-330.

Daubenmire, R. F. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington State University, Agricultural Experiment Station. 131 p.

Eckert, R. E., Jr. 1957. Vegetation-soil relationships in some Artemisia types in northern Harney and Lake Counties. Corvallis, OR: Oregon State University. 208 p. Dissertation.

Francis, Richard E. 1983. Sagebrush-steppe habitat types in northern Colorado--a first approximation. In: Southwestern habitat types; Proceedings of Workshop; 1983 April 6-8; Albuquerque, NM. U.S. Department of Agriculture, Forest Service, Southwestern Region: 67-71.

Goodrich, Sherel; McArthur, E. Durant; Winward, Alma, H. 1985. A new combination and a new variety in Artemisia tridentata. Great Basin Naturalist. 45: 99-104.

Griffiths, D. 1902. Forage conditions on the northern border of the Great Basin. Bulletin 15. Washington, DC: U.S. Department of Agriculture, Bureau of Plant Industry. 52 p.

Hann, W. J. 1982. A taxonomy for classification of seral vegetation of selected habitat types in western Montana. Moscow, ID: University of Idaho. 235 p. Dissertation.

Hironaka, M. 1979. Basic synecological relationships of the Columbia River sagebrush type. In: The sagebrush ecosystem--a symposium. Logan, UT. Utah State University: 27-32.

Hironaka, M; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types in southern Idaho. Bulletin No. 35. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 44 p.

Hugie, U. K.; Williams, E. W.; Passey, H. B.; Ball, D. E. 1974. Soil-vegetation-climate relationships: Mimeograph Report. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 91 p.

Huschle, G.; Hironaka, M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33: 179-183.

Jensen, M. E.; Peck, L. S. 1986. Sagebrush community types of northeastern Nevada and their relationship to soil properties. Boise, ID. Abstracts of 40th Annual Meeting, American Society for Range Management. No. 124.

Johnson, Kendall L. 1987. Sagebrush types as ecological indicators to integrated pest management (IPM) in the sagebrush ecosystem of western North America. In: Integrated pest management on rangelands: state of the art in the sagebrush ecosystem: ARS-50. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service: 1-10.

Kennedy, P. B.; Doten, S. B. 1901. A preliminary report on the summer ranges of western Nevada sheep. Bulletin 51. Reno, NV: University of Nevada, Agricultural Experiment Station. 54 p.

McLean, A. 1970. Plant communities of the Similkameen Valley, British Columbia, and their relation to soils. Ecological Monographs. 40: 403-424.

Mueggler, W. F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Poulton, C. E.; Tisdale, E. W. 1961. A quantitative method for the description and classification of rangeland vegetation. Journal of Range Management. 14: 313-321.

Schlatterer, E. F. 1972. Plant communities found in the Sawtooth, White Cloud, Boulder and Pioneer Mountains. Ogden, UT: U.S. Departmert of Agriculture, Forest Service, Intermountain Region. 111 p.

Shantz, H. L.; Zon, R. 1924. Atlas of American Agriculture Part 1. The Physical base of agriculture. Sec. E: Natural vegetation. Washington, DC: U.S. Department of Agriculture, Bureau of Agricultural Economics.

Schultz, L. M. 1986. Taxonomic and geographic limits of Artemisia subgenus Tridentatae (Beetle). In: Proceedings - Symposium on the biology of Artemisia and Chrysothamnus. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 20-28.

Tisdale, E. W.; Hironaka, M.; Fosberg, M. A. 1969. The sagebrush region in Idaho--a problem in range resource management. Bulletin 512. Moscow, ID. University of Idaho, Agricultural Experiment Station. 15 p.

Tisdale, E. W.; Hironaka, M. 1981. The sagebrush-grass region--a review of the ecological literature. Bulletin No. 33. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 31 p.

Tisdale, E. W.; Bramble-Brodahl, Mary. 1983. Relationships of site characteristics to vegetation in canyon grasslands of west central Idaho and adjacent areas. Journal of Range Management. 36: 775-779.

Tueller, P. T. 1962. Plant succession on two Artemisia habitat types in southeastern Oregon Corvallis, OR: Oregon State University. 249 p. Dissertation.

Ward, G. H. 1953. Artemisia--Section Seriphidium in North America--a cytotaxonomic study. Palo Alto, CA: Contributions from Dudley Herbarium. 4: 155-205.

Winward, A. H. 1977. Taxonomy and ecology of big sagebrush. Moscow, ID: University of Idaho. 80 p. Dissertation.

Winward, A. H. 1980. Taxonomy and ecology of sagebrush in Oregon. Bulletin 642. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 15 p.

Zamora, B.; Tueller, P. T. 1973. Artemisia arbuscula, A. longiloba and A. nova habitat types in northern Nevada. Great Basin Naturalist. 33: 225-241.

USING HABITAT CLASSIFICATION SYSTEMS IN UPLAND GAME BIRD HABITAT

Donald A. Klebenow

ABSTRACT: Patterns of sage grouse habitat use often correspond with delineations of range or ecological sites. Information of this type is of value to resource managers because it identifies which ecological sites are important for management of wildlife such as sage grouse. Since range site descriptions are of climax vegetation and the habitat that upland game prefer may not be climax, it is desirable that site descriptions include descriptions of the site's seral stages.

INTRODUCTION

The systems of land classification based on vegetation devised by range and forest ecologists provide a language that facilitates communication between wildlife habitat researchers and other researchers and managers. These classifications serve two purposes: describing the setting of research study areas and projecting applications of research findings to areas of similar capabilities (Hironaka 1984).

Wildlife researchers have used a variety of systems. For a very general habitat or study area description Kuchler's (1964) potential natural vegetation classification has sometimes sufficed. His classification is extensive in its treatment, covering the entire United States. The vegetation types are too broad to be very useful in habitat description and in the Great Basin where I work the vegetation classification for all my study areas would be sagebrush steppe. But that would include the habitat of sage grouse (Centrocercus urophasianus) and chukar partridge (Alectoris graeca) plus part of the habitat of California quail (Lophortyx californica) and blue grouse (Dendragapus obscurus). It is useful only in very general terms.

A more specific classification has been presented by Dealy and others (1981) in Wildlife Habitats in Managed Rangeland--The Great Basin of Southeastern Oregon. They recognize the various species and subspecies of genus Artemisia and present 11 vegetation types dominated by sagebrush within Kuchler's (1964) sagebrush steppe classification. Twenty-eight plant community types are used to describe Oregon's rangelands. They are identified mainly by tree and shrub dominant species and in some cases, dominant grass species in the understory. Their use is to explain the relationship of terrestrial vertebrates to plant communities in southeastern Oregon (Maser and others 1984a, 1984b).

The Dealy and others (1981) classification approximates the habitat type classification of Daubenmire (1952) and others (Mueggler and Stewart 1980; Hironaka and others 1983). In some cases Dealy and others (1981) are more general than the habitat type classification, for example, the basin big sagebrush/bunchgrass community where the grasses are not specifically identified. Others of their community types parallel the habitat type concept as the communities are more specifically named. The western juniper/big sagebrush/Idaho fescue community is one such case. It is unfortunate that they used the more general classification in part. It would be desirable if habitat types would become accepted as the standard for plant community classification, thus the system by which other classifications would be compared.

EXPERIENCE WITH SYSTEMS

I personally first used habitat types to classify and describe a mule deer winter range in western Montana (Klebenow 1962). Within the Pseudotsuga menziesii/Physocarpus malvaceus and Pinus ponderosa/Physocarpus malvaceus habitat types of the study area there were sites that differed in plant composition and abundance that related to more or less use by mule deer than other sites. Thus, it was necessary to divide the habitat into units more homogeneous than the two habitat types. I did that and eventually outlined 13 different vegetation community types based on differences in plant composition and plant density. The point is, in order to adequately describe the use of habitat types by wildlife, it was necessary to subdivide the habitat types into more uniform units.

Since that time, the range site or ecological site concept have also been developed to classify habitats into more homogeneous units. The Bureau of Land Management and the Soil

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Donald A. Klebenow is Professor of Wildlife Management, Department of Range, Wildlife and Forestry, University of Nevada, Reno.

Conservation Service are two Federal agencies using these classifications. Their use is increasing.

Range or ecological sites were used for basic habitat inventory on two sage grouse studies with which I have been associated. These site classifications have great potential for use in wildlife habitat management, for patterns of habitat use by birds often corresponded with delineations of range sites. On the Saval Ranch in northeastern Nevada all the strutting grounds were located within the Loamy, 8-10 Inches Precipitation Zone Range Site, 1 of 17 range sites on the study area. In northwestern Nevada on the Sheldon National Wildlife Refuge four upland ecological sites and one meadow site contained virtually all the habitat used by sage grouse. In total 28 ecological sites were identified and mapped on the entire refuge. On the uplands the birds used the ecological sites that contained a combination of Wyoming big sagebrush (*A. tridentata wyomingensis*) and low sagebrush (*A. arbuscula*). Monotypic stands of either shrub species were seldom used except during the winter. During the winter the mixed species sagebrush sites were used but the monotypic sagebrush Ecological Site 690, Arid Loamy Terrace (table 1) provided sagebrush forage when sagebrush on higher elevation sagebrush sites was not available due to snow cover. This site was used only during the winter months.

These studies were not done to test the relationship between sage grouse habitat selection and ecological site classification, but the relationship was obvious when the bird habitat use was evaluated and compared to range site inventory maps.

Table 1--Ecological site description of Arid Loamy Terrace, Ecological site 690, High Desert Resource Province, Shrub Climax Type (Upland). The location of the typical example is Sec. 13, T34S, R27E, Hart Mountain National Wildlife Refuge, Lake County, OR (Anderson 1978)

ARID LOAMY TERRACE

Physiography: This site occurs on nearly level to gently sloping basin terraces. Slope gradients vary from 2 to 6%. Elevation is about 4,500 to 5,500 feet (1570-1675 meters).

Climate: Precipitation averages 8 to 11 inches (20-28 cm) most of which comes in October through June as snow and spring-autumn rain. About 30% of the total precipitation comes during the growing season which begins about April 1 and ends about July 1. The growing season is relatively cold, being typical for the High Desert Province which has average mean minimum/maximum temperatures for April 29/60 °F (-.7/15.6 °C); May 35/67 °F (1.7/20 °C); June 40/74 °F (4.4/23 °C). Recharge of available soil moisture begins in November but the average daytime temperature at that time is below 39-40°F (4°C) and there usually is little or no autumn regrowth on this site.

Soils: The soils on this site have loamy surface layers and loamy to moderately fine textured subsoils. They are gravelly throughout and the subsoil may be stony. They are underlain by hardpan or cemented gravel and stones at a depth of about 18 inches (46 cm). The significant soil series include: Olson loam.

Original Native (climax) Vegetation: Species commonly found on this site which did not occur in the climax stand are listed and marked 0 in occurrence.

Approximate Percent Ground Cover

Bare ground 10-20% Mosses & Lichens T (Trace) Gravel, stone, rock 10-20% Total vegetational cover is about 70-80%

Grasses (max 50%)		Forbs (max 5%)		Shrubs (max 20%)	
Bluegrass, Sandberg	2	Buckwheat, snow	1	Hopsage	T
Brome, cheatgrass	0	Cryptantha	T	Horsebrush, littleleaf	1
Needlegrass, Thurber	2	False-yarrow	1	spiny	T
Ricegrass, Indian	15	Hawksbeard, tapertip	1	Rabbitbrush, threadlaeaf	1
Webber	5	Loco, specklepod	1	Sagebrush, big	20
Squirreltail	5	woollypod	T		
Wheatgrass, bluebunch	20	Lupine	1		
foxtail	T	shortstem	T		
streambank	2	Milkvetch, hangingpod	1		
		Mustard (yellow)	T		
		Pepperweed	T		
		Phlox (annual)	T		
		longleaf	T		

INFORMATION VALUES

Information of this nature is of value to resource managers because it identifies which ecological sites are valuable for management of wildlife such as sage grouse. It aids in communications between research and management but it fails in that it does not identify to habitat managers the conditions sought by the birds. It permits the application of research findings to other areas of similar capabilities only in a general way, that similar areas have similar potential. It does not identify the habitat conditions that must be duplicated to be successful habitat managers.

Within each of the existing ecological sites on these two different research areas there was variation in terms of shrub density, understory composition, and general range condition. Bird use was not evenly distributed throughout each site but related to existing conditions or plant communities. The site descriptions based on climax almost never described the habitats occupied by sage grouse.

For example, on the Sheldon National Wildlife Refuge the Ecological Site 690, Arid Loamy Terrace, tended to be in poor conditon dominated by big sagebrush with little herbaceous or grass understory. In climax condition it never would contain many forbs, 5 percent ground cover maximum, but there could be 20 percent cover of Indian and Webber ricegrasses (Orozopis hymenoides and O. webberi, respectively) and 20 percent bluebunch wheatgrass (Agropyron spicatum) (table 1). Cheatgrass brome (Bromus tectorum) and Sandberg bluegrass (Poa sandbergii) were the principal grasses at the time of the study and had greater abundance than given in the site description. Judging from the notable lack of understory this ecological site was much different than it would be if the range condition was improved.

The study of sage grouse indicated no value for sage grouse except in winter. This probably is a false conclusion relative to the potential for sage grouse because if the site were somewhat close to the potential as indicated in the site description, it probably would have value for nesting and brood rearing even though it was one of the more arid sites on the study area. Historically the 8-11 inches precipitation zone in Nevada produced sage grouse (Klebenow 1984-1985). Presently, the spring, summer, and fall grouse populations are nearly always found in zones above 10 inches precipitation.

Improving the condition of Ecological Site 690 (table 1), would supposedly lead to a decline in the amount of big sagebrush cover. If site potential was reached, 20 percent of big sagebrush cover should be adequate for all seasons including winter. Achievement of the climax vegetation potential on this site would reach its highest potential for year-long use by sage grouse.

OTHER TYPES OF SITES

But what of other sites? The climax potential is often not the best habitat management goal; consider ruffed grouse (Bonasa umbellus).

Gullion and Alm (1983) and Gullion (1984) in Minnesota have the habitat needs for ruffed grouse well defined. These grouse do best in quaking aspen (Populus tremuloides) dominated habitat, seral communities in coniferous forest. Within the aspen seral stage an interspersion of various aged aspen stands produces the most grouse.

Greater prairie chickens (Tympanuchus cupido) are another grouse that seek subclimax habitat, in this case burned tall grass prairie (Westemeier 1972). In forests, bobwhite quail (Colinus virginianus) also prefer subclimax habitat (Rosene 1969).

For the species where subclimax habitat is the goal of wildlife habitat management, ecological site descriptions do little other than identify the ecological name of these sites. It would be much more desirable if the habitat that exists could be categorized ecologically and that site descriptions would include descriptions of the site's seral stages. If that were achieved, then full communication would be possible between wildlife and land managers and ecological sites would be the common habitat management language.

WORKING TOWARD THE GOAL

Maybe the detail that I envision as desirable is more than we ever will achieve. I can see that the outlining of plant composition for all the seral stages of each ecological site would be a complicated task. Rating the wildlife potential for each stage will be another involved undertaking. Research would be necessary in a lot of cases to get a full understanding of the relationships between the successional stages of an ecological site and the reaction of wildlife. But I believe we should work toward this goal. It would allow for a more objective approach to wildlife habitat management for upland game birds and other wildlife than presently exists.

REFERENCES

Anderson, E. William. 1978. Range site handbook for the High Desert Resource Province, Oregon. Portland, OR: U.S. Department of Agriculture, Soil Conservation Service. Unpublished report [mimeo].

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Dealy, J. Edward; Leckenby, Donavin A.; Concannon, Diane M. 1981. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon. Plant communities and their importance to wildlife. Gen. Tech. Rep. PNW-120. Portland, OR: U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, Bureau of Land Management. 66 p.

Gullion, Gordon. 1984. Grouse of the north shore. Oskosh, WI: Willow Creek Press. 136 p.

Gullion, Gordon W.; Alm, A.A. 1983. Forest management and ruffed grouse populations in a Minnesota coniferous forest. Journal of Forestry. 81(8):529-532, 536.

Hironaka, M. 1984. Habitat type, range site and community type. In: McArthur, E.D.; Welch, B.L. compilers. Proceedings, Symposium on the Biology of Artemisia and Chrysothamnus. 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 15-18.

Hironaka, M.; Fosberg, M.A.; Winward, A.H. 1983. Sagebrush-grass habitat types of southern Idaho. Forest, Wildlife, and Range Experiment Station Bulletin 35. Moscow, ID: University of Idaho. 44 p.

Klebenow, Donald A. 1962. Ecology and productivity of a montane forest winter deer range, western Montana. Missoula, MT: University of Montana. 93 p. Thesis.

Klebenow, Donald A. 1984-1985. Habitat management for sage grouse in Nevada. The World Pheasant Association Journal. X:34-46.

Kuchler, A. W. 1964. The potential natural vegetation of the conterminous United States. Special Publication 36. New York, NY: American Geographical Society. 160 p.

Maser, Chris; Thomas, Jack Ward; Anderson, Ralph G. 1984a. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon. The relationship of terrestrial vertebrates to plant communities, part 1, text. Gen. Tech. Rep. PNW-172. Portland, OR: U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, Bureau of Land Management. 25 p.

Maser, Chris; Thomas, Jack Ward; Anderson, Ralph G. 1984b. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon. The relationship of terrestrial vertebrates to plant communities, part 2, appendices. Gen. Tech. Rep. PNW-172. Portland, OR: U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, Bureau of Land Management. 237 p.

Mueggler, Walter F.; Stewart, W.L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Rosene, Walter. 1969. The bobwhite quail, its life and management. New Brunswick, NJ: Rutgers University Press. 418 p.

U.S. Fish and Wildlife Service. 1980. Sheldon National Wildlife Refuge renewable natural resources management plan. Final environmental impact statement. Portland, OR: U.S. Department of Interior.

Westemeier, Ronald L. 1973. Prescribed burning in grassland management for prairie chickens in Illinois. In: Komarek, E.V., Sr. compiler. Proceedings, Tall Timbers Ecology Conference 12. June 8-9, 1972; Lubbock, TX. Tallahassee, FL: Tall Timbers Research Station: 317-338.

SPECIAL CONSIDERATIONS WHEN CLASSIFYING RIPARIAN AREAS

Alma H. Winward and Wayne G. Padgett

ABSTRACT: Our ability to manage riparian areas will improve as we gain a better understanding of their ecology. Classification of these areas into community types and riparian complexes is helping to provide this understanding. Some ecological features unique to riparian settings are discussed.

INTRODUCTION

In our efforts to develop vegetation classifications for forest and rangeland settings, we somehow failed to adequately treat the riparian areas. In past classifications we either lumped riparian with upland types or, at best, divided riparian into the three broad categories of wet meadow, dry meadow, or browse shrub (USFS 1982). More recently, with the emphasis on better riparian management, there has been a major effort to refine classifications of these relatively small, but important, areas. Some of these efforts have centered around water or hydrologic characteristics (Rosgen 1985). Others have been based more on use oriented activities such as fish or wildlife habitat (Pfankuch 1978).

Current work by the Intermountain Region of the USDA Forest Service has emphasized a classification based on vegetation/site characteristics. The vegetation units are referenced as community types (CT's) and the site units as riparian complexes. Community types represent repeating stands (patches or islands) of similar vegetation with no reference made to successional status. Types are named after one or two dominant plant species in the community (Youngblood and others 1985a; Youngblood and others 1985b). Examples would be the narrowleaf cottonwood/Kentucky bluegrass (Populus angustifolia/Poa pratensis) CT or the tufted hairgrass (Deschampsia caespitosa) CT. Thus far, the classification includes a little over 100 CT's, about 80 percent of those we expect to find on National Forest lands in our Region.

The riparian complex represents a unit of land that supports or may potentially support a similar grouping of community types. It is identified on the basis of its overall geomorphology, and substrate, as well as its general vegetation pattern. It is named on the basis of the most common or prominent CT present, along with special features of the site on which it occurs. Examples would be the Alder/Dogwood-Steep Gradient-Narrow Valley Bottom Complex or the Tufted Hairgrass-Low Gradient-Wide Valley Bottom Complex.

The concept of the riparian complex is based on similar reasoning as that of the habitat type described by Daubenmire (1952). It is similar in that each, the habitat type and the riparian complex, represents units of land that have an inherent environmental potential to support certain kinds of vegetation. A major difference in the two is that the habitat type is based on a grouping of individual species (the association) while the riparian complex is based on a grouping of community types.

We are still in the early stages of identifying and naming riparian complexes. Thus far, these complexes appear to have high utility for serving as units for developing integrated management opportunities in the riparian setting.

SPECIAL FEATURES

As we began to look into the more detailed riparian classifications, we soon discovered special or unique problems and new challenges. One of the more perplexing difficulties encountered was the relatively small size and mosaic pattern of the CT's. Individual stands of a CT may range from a few square feet in size to several acres. Any one section of a stream or meadow is usually composed of numerous stands of several CT's. This became less of a problem as we eventually began to see and understand the pattern of these stands. Generally, one riparian complex has only four to eight CT's represented, with the distribution or pattern tied to the soils or, most often, water table features within that complex. The predictability of certain CT's to environmental settings soon helped us minimize the initial frustrations we had when we viewed them as an intermixed "scramble" of types. However, we did have to continue to think on a different scale (area basis) than we had been used to on surrounding upland types since one acre of riparian generally has several CT's present on it.

Another difficulty encountered in our classification efforts was the extent of disturbances these areas have received. Livestock, timber harvesting, recreational activities, and roads

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Authors are Regional Ecologist and Ecologist, respectively, Intermountain Region, Forest Service, U.S. Department of Agriculture, Ogden, UT.

potentially impact the vegetation and soil resources in these areas. Unlike the surrounding forest and rangeland types, most damaging influences are not limited to the area where they occur. Instead, many influences become cumulative down stream or lower in the watershed. This often makes it difficult to understand or to assign cause to particular disturbances.

"Natural" events also can cause detrimental impacts in the riparian setting. Fire, insect and disease outbreaks, and cyclic beaver activity tend to create everchanging environmental settings. Uncommon high run-off events can cause down-cutting of stream channels with subsequent heavy deposition elsewhere, and often, the relocation of stream channels. This feature alone can result in an almost continual readjustment of successional processes in some areas.

Because riparian ecosystems are often subjected to changes in the microenvironment, we have found the term "vegetation climax" (as used in the context of a self-perpetuating condition where species composition on a particular area becomes somewhat stabilized) is not always achieved, even under so-called "natural conditions." The exceptions include a few specially armored settings where bedrock or large cobbles/boulders keep the stream channel intact, or some low-gradient meadow situations that have stable enough settings for the vegetation to reach a balance with the environment.

In the remaining riparian areas there seems to be a continual breaking down or building up process that seldom allows the vegetation to have long-term stability. Lakes and ponds fill with sediments while river and stream channels move about in the valley floor with accompanying changes in nutrients and water table levels. Consequently, even under non-human influenced settings, the natural vegetation often represents only the mid-to late-seral stages, not the classical climax vegetation. Additionally, the probability is high that the seral stages will be relatively short lived. Major changes can occur in 10 to 20 years in riparian areas in contrast to successional process in surrounding upland vegetation where changes may require hundreds or even thousands of years.

This history of rapid change has produced some interesting riparian species adaptations. Many of the cottonwood, alder, birch, and willow species require, or at least regenerate much better, on disturbed or open ground. These species are very poor competitors in dense grass or heavily sodded settings (Winward 1986). Instead, they depend on newly developed sand and gravel bars, freshly broken banks, or seasonal deposition areas in order to regenerate and establish. Similarly, many grass and sedge species establish in new sections of a stream by anchoring chunks of sod broken from banks upstream. All these processes indicate a history of continual disturbances in riparian settings.

The continual disruption of succession in riparian areas does not necessarily prevent us from developing classifications based on potential of a site, nor does it leave us without an ability to use vegetation communities--in our case the CT's, as descriptors of condition of an area. It means, instead, that we must realize we are generally working with communities that are not end-points in succession as we have tended to evaluate against on upland areas.

REALIGNMENT OF TYPES

We currently are evaluating a feature in riparian areas that is somewhat unique from processes on upland types. It appears that a common characteristic of the vegetation units within a riparian complex involves a swapping or realignment of stands of CT's. For example, a stand of one CT can establish and exist for several years in one specific location within the complex (fig. 1A, B). Then, as the environment supporting it is altered, such as a ground water change due to a changing of the stream channel (fig. 1C), that particular CT may reoccur somewhere else in the complex where the site features are now suitable (fig. 1D). Another type suited to the newly developed setting on the original area initiates development. Normally both types were present in that particular complex. Over time, stands of these two types have merely switched places. This realignment of stands of different CT's is unique from upland settings where stands of types may occur only on specific portions of a geographic area and those locations are essentially permanently set.

We are attempting to determine how much variability there is in composition of CT's in one complex, over time. In the process of interchanging locations within the complex, do the CT's remain in approximately the same relative composition even though individual stands move about in the complex? Also, is there enough commonality in CT composition in two geographic areas (the same complex in two different locations) that we can predict composition or composition potential from one geographic location to another? Our initial efforts suggest there is and that we can use this feature to help us understand and manage riparian areas. If there is a set kind and number of CT's within a complex in undisturbed conditions, and if new types enter the scene when unnatural disturbing factors, such as intense livestock grazing and trampling, or soil compaction from recreational activities, are present (fig. 1E), methods can be devised to quantitatively measure the degree of impact. For example, percent change in CT composition to CT's that indicate human-related activities can be used to measure degree of impact. In our riparian areas common new communities that come about as result of disturbances include: Kentucky bluegrass, willow/Kentucky bluegrass, red top (Agrostis stolonifera) or various thistle (Cirsium) species. The percentage of the composition of these types in a complex is an indicator of impact.

Complexes appear to be controlled by relatively stable factors such as stream gradient, valley bottom width, and elevation (geomorphology) or sometimes, by the size and pattern of water discharge, which is determined primarily by climate. Seldom do human-related influences change features of the overall geomorphology. Instead, human-caused influences normally involve changes in specific water

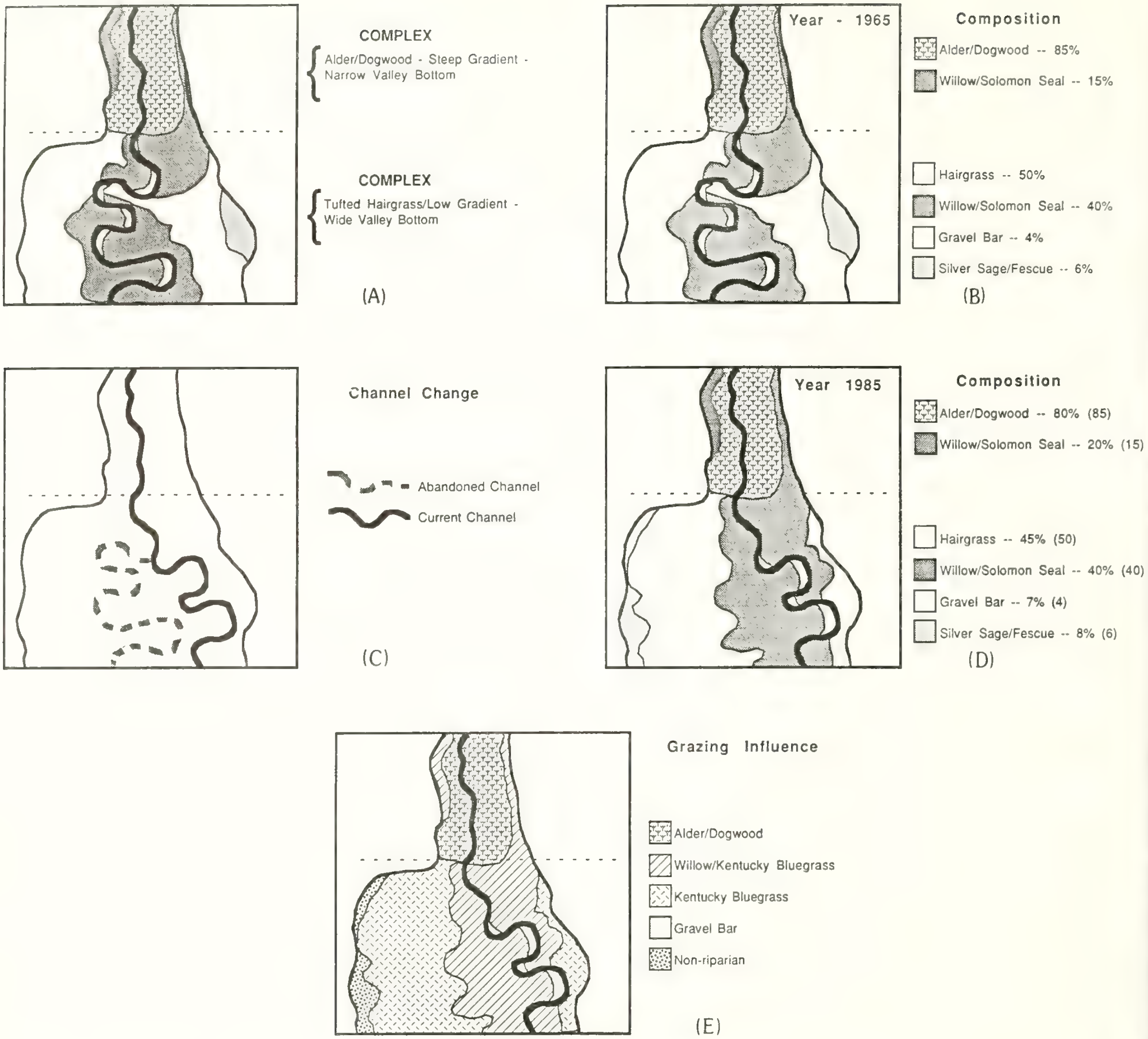


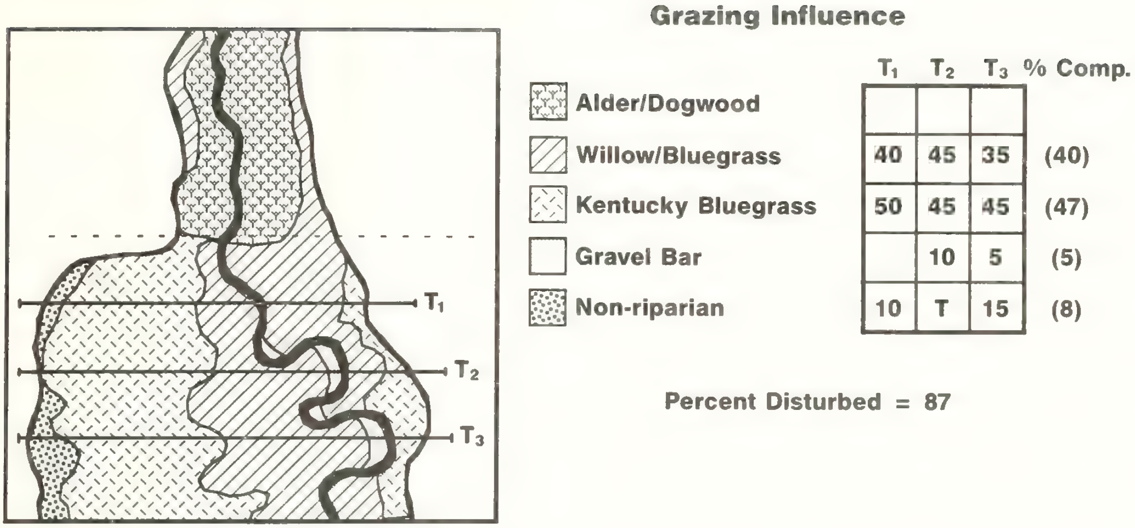
Figure 1--Graphical display of a typical riparian area in the Intermountain Region showing: (A) two riparian complexes along with stands of several community types within each complex; (B) community type composition in two riparian complexes during sampling period 1965; (C) a stream channel change that potentially may influence location of stands of the community types; (D) realignment of stands of each community type as a result of the channel change (sampling period 1985); and (E) common changes in kinds of community types in two complexes as a result of unnatural disturbance factors such as intensive grazing.

table or impact on certain plant species. These influences normally show up in changes in the CT composition within the complex.

We are developing sampling procedures that will help us monitor changes taking place in the riparian settings as a result of human-related activities. The line intercept method similar to that designed for use in obtaining individual species cover (Canfield 1941) is being tested as an approach for obtaining CT composition (fig. 2). Unmodified or minimally modified riparian settings are used to obtain representation of CT composition in least-altered status. These then may be used as standards to measure CT composition changes in settings with various stages of disturbance. Other common methods for measuring species density, cover, or frequency may also be used for more detailed evaluations (USDA 1986).

DISCUSSION

Development of riparian area classifications has been slow relative to upland classifications. This may have been related to their small size and



	T_1	T_2	T_3	% Comp.
▨ Alder/Dogwood				
▨ Willow/Bluegrass	40	45	35	(40)
▨ Kentucky Bluegrass	50	45	45	(47)
☐ Gravel Bar		10	5	(5)
▨ Non-riparian	10	T	15	(8)

Figure 2--Use of the line intercept method to measure amount of change in community type composition after unnatural disturbances.

complicated nature. Much effort is currently in progress to overcome this deficiency.

In the Intermountain Region of the Forest Service, we are finding that classification of these areas into riparian complexes (vegetation/site units) and into the further refined community types (vegetation units) has helped us gain a better understanding of the riparian setting. The complexes and/or community types serve as stratification units to help us understand features of the site, including the water, soil, and broad vegetational features. We are finding a definite relationship, for example, between the CT's and/or the complexes and the amount of natural bank breakage (Burton and others 1985; Winward 1986). Different CT's or complexes are also selected or preferred by livestock seasonally. Use of these types of classification units can help us answer questions about riparian area improvements. Questions such as: Which section of the stream should have willows? Which willow species should be used for rehabilitation? What species options do we have for understory establishment? Where and what type of instream structures would be appropriate? Similarly, knowledge of the tie between wildlife and fish to CT's or complexes can improve our efforts to provide better habitat. Finally, it should help us determine what type of research is needed to help us better manage these areas and, especially, where results of specific studies are applicable.

REFERENCES

Burton, L. A.; Forsgren, H. L.; Ashton, A. W. 1985. Riparian community types and management implications within the Sawtooth National Recreation Area (SNRA) of Central Idaho. Abstract, Annual Meeting of Soc. for Range Manage. Salt Lake City, UT. p. 19.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry. 39:388-394.

Daubenmire, R. 1968. Plant communities. A textbook of plant synecology. New York: Harper and Row Publishers. 300 p.

Pfankuch, D. J. 1978. Stream reach inventory and channel stability evaluation: A watershed management procedure. U.S. Department of Agriculture, Forest Service, Northern Region. R1-75-002. 26 p.

Rosgen, David L. 1985. A stream classification system. In: Riparian Ecosystems and Their Management - An Interagency North American Riparian Conference. Tucson, AZ. p. 91-95.

U.S. Department of Agriculture, Forest Service. 1982. Range Analysis Handbook, FSH 2209.21. Intermountain Region, Ogden, UT.

U.S. Department of Agriculture, Forest Service. 1986. Range Analysis Handbook, FSH 2209.21. Intermountain Region, Ogden, UT.

Winward, Alma H. 1986. Vegetation characteristics of riparian areas. In: Kie, John G.; Laudenslayer, William F., Jr., eds. Transactions of the Western Section of the Wildlife Society. Sparks, NV. Sacramento, CA: The Western Section of the Wildlife Society. 22:98-101.

Youngblood, A. P.; Padgett, W. G.; Winward, A. H. 1985a. Riparian community type classification of northern Utah and adjacent Idaho. U.S. Department of Agriculture, Forest Service, Intermountain Regional Office Contract Report. Ogden, UT. Draft. 104 p.

Youngblood, A. P.; Padgett, W. G.; Winward, A. H. 1985b. Riparian community type classification of eastern Idaho-western Wyoming. U.S. Department of Agriculture, Forest Service, Intermountain Regional Office Contract Report, Ogden, UT. 78 p.

UTILITY OF VEGETATION-BASED LAND CLASSES FOR PREDICTING FOREST REGENERATION AND GROWTH

Albert R. Stage

ABSTRACT: Habitat types representing potential vegetation are important indicators of forest productivity. Tree regeneration and growth rates can be estimated using habitat types such as those developed for northern Idaho. In the Stand Prognosis Model, most of the equations for regeneration and growth rates include habitat effects. For each species and equation, habitat types are combined into groups that respond similarly. However, the composition of the groups differs from species to species and from equation to equation so that, overall, each habitat type is unique. A land classification system based on habitat types is useful for growth and yield modeling, and hence in land management planning, if it meets the following criteria: (1) applies to all forest lands in the management unit; (2) is mappable into homogeneous units of 2 to 10 acres; (3) is unchanging with respect to stage of succession; and (4) evolves conservatively.

VEGETATION TYPES AS PRODUCTIVITY INDICATORS

One of the many expectations for vegetation-based land classification has been that the classes would indicate forest productivity. Evidence supporting this presumption has been available for quite some time. Etter (1949) in Switzerland described the relation of different site-types to productivity. In the northeastern U.S., Westveld (1951, 1952, 1954) proposed that climax forest type provided a sound basis for silvicultural prescription and for rating productivity, although his reports presented only a rank-ordering of sites by ground vegetation. Gagnon and MacArthur (1959) reported that ground vegetation could be used to indicate differences in diameter, height, and survival of white spruce plantations. And in Alberta, Canada, Corns and Pluth (1984) found that vegetational indicators added more accuracy to the prediction of growth than did soil and site properties.

In much of the United States, foresters have equated productivity with site index. Hodgkins (1961) reported the use of indicator plants to predict site index for longleaf pine (Pinus palustris), as did Roe (1967) for western larch Larix occidentalis), and MacLean and Bolsinger (1973a) for ponderosa pine (Pinus ponderosa).

Daubenmire (1961), however, showed that trends of ponderosa pine height growth with age differed markedly among habitat types, which were defined by potential climax communities. He demonstrated that the customary use of a single set of site-index curves for all sites in a region masked the relation of productivity to habitat types. Following his lead, Monserud (1984) produced a system of site index curves for Douglas-fir (Pseudotsuga menziesii var. glauca) in which curve shape varied among groups of habitat types that shared the same overstory union.

Habitat types also help explain differences in the relation of site index for one species to site index for an associated species in the same stand (Deitschman and Green 1965; Stanek 1966). These relations result from species differences in conditions for optimal growth.

Although it has been shown that there is substantial variation in site index between habitat types, it was also obvious that there is much variation in site index within a habitat type. Monserud (1984) working with inland Douglas-fir, for example, found standard deviations within habitat series of ±10 to ±14 feet of site index (base age 50 years) while the range among six series means was only 19 feet. For western white pine site index, some of the variation within a habitat type was found to depend on aspect and slope (Stage 1976).

The capacity of a site to support a vigorous stand at a particular density has been recognized as a component of forest productivity that is not always related to the height growth potential represented by site index (MacLean and Bolsinger 1973b). Hall (1983), in his definition of "growth basal area," provided an objective index of carrying capacity. His index expresses the basal area at which dominant, 100-year-old trees will grow 1 inch in radius per decade. His measure is closely related to the self-calibration procedure used by Stage (1981) to compare diameter increments at a given stocking level. Both procedures were designed to quantify differences in productivity between stands having the same height growth potential. Hall showed that his growth basal area index varied among community types. Similarly, Pfister and others (1977) found differences in basal area carrying capacity among habitat types in Montana.

RELATIONS OF HABITAT TYPES TO STAND DYNAMICS

Habitat types have much more profound relations to growth and yield, and hence to productivity, than is represented by site index variation. The Stand

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Albert R. Stage is Principal Mensurationist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Moscow, ID.

Prognosis Model (Stage 1973; Wykoff and others 1982) will be used to illustrate these effects, because the Inland Empire variant of this model is the only generally used yield forecasting system in which habitat types in concert with physical site factors but not site index indicate differing growing conditions. Not all variants of the Stand Prognosis Model use habitat types, because data available to calibrate the model for many regions did not include habitat type, but did include site index.

Habitat types play a key role in all three major components of the model:

- -- Regeneration (Ferguson and others 1986)
- -- Accretion (Hatch 1980; Stage 1975; Wykoff 1983,1986; Wykoff and others 1982)
- -- Mortality (Hamilton 1986; Hamilton in preparation)

Regeneration

In the regeneration component, habitat types are significant predictors of (1) probability of stocking, (2) numbers of seedlings given that the plot is stocked, (3) species presence in the regeneration, and (4) height growth of newly established seedlings.

Accretion

Any model of accretion rates requires some measure of site quality or its separate factors such as growing season length and heat, moisture, and nutrient availability. Whereas site quality is essentially a continuous variable, or a set of continuous variables, land classes have discrete boundaries, at least in concept. Therefore, one would a priori expect a continuous variable such as site index to be a more effective representation of site quality than variables defined by discrete classes such as habitat types.

Of the elements of the accretion component, diameter increment was the first in which habitat types were tested as an alternative to site index. The diameter increment model introduces habitat type in two roles. Because the model has a logarithmic dependent variable, the intercept terms, which depend on habitat types, multiply the rates represented by the other terms. In addition, the coefficients of stand density differ by habitat type, representing differences in carrying capacity of the site. Wykoff's (1983) analyses showed that some habitat types could be combined into groups that did not differ significantly, but that the groupings differed for each of the 11 tree species in his data. Of 28 habitat types, only two pairs were combined in the same way for all species--and these were types for which there were few data. Here, as for height growth, species are responding differently to the factors being represented by habitat types. Ten-year diameter increment predicted by this model is shown for differing habitat types within the St. Joe National Forest in table 1. These values are computed for a dominant Douglas-fir of 10-inch d.b.h., growing on flat ground in a stand having 60 percent of the basal area carrying capacity for the type. Although there is a range of 0.6 inches in these estimates, the range among National Forests within just the Abies grandis/Clintonia uniflora habitat type (table 2) is equally large.

Table 1--Ten-year diameter increments predicted by the Prognosis Model for dominant Douglas-fir of 10-inch d.b.h growing at the indicated densities on flat ground in the St. Joe National Forest, ID

Habitat type	Density (60% of carrying capacity)	10-yr diameter increment (inside bark)
	ft^2	Inches
Pseudotsuga menziesii/ Physocarpus malvaceous	202	1.39
Abies grandis/ Clintonia uniflora	247	1.39
Thuja plicata/ Clintonia uniflora	286	1.59
Tsuga heterophylla/ Clintonia uniflora	254	1.50
Abies lasiocarpa/ Clintonia uniflora	286	1.44
Tsuga mertensiana/ Xerophyllum tenax	169	1.21
Abies lasiocarpa/ Xerophyllum tenax	254	1.19
Abies lasiocarpa/ Menziesia ferruginea	260	1.12
Tsuga mertensiana/ Menziesia ferruginea	228	0.99

Table 2--Ten-year diameter increments predicted by the Prognosis Model for dominant Douglas-fir of 10-inch d.b.h. growing on flat ground in the Abies grandis/Clintonia uniflora habitat type at a density of 247 ft^2 of basal area by National Forest location

National Forest	10-yr diameter increment (inside bark)
	Inches
Nezperce	1.23
Clearwater	1.28
St. Joe	1.39
Coeur d'Alene	1.11
Kaniksu	1.10
Bitterroot	0.70
Lolo	0.78
Kootenai	0.96
Flathead	0.97
Colville	0.98

Two studies have tested the sufficiency of habitat types for representing site quality in diameter growth models. For six species represented in 102 permanent growth plots in the *Abies grandis/Pachistima myrsinites*, the *Tsuga heterophylla/Pachistima*, and the *Thuja plicata/Pachistima* habitat types, I found that these three habitat types accounted for as much or more variation as did reliable estimates of site index.

A further, rather rigorous, test of the adequacy of habitat types (used in conjunction with slope, aspect, elevation, and geographic location) was conducted by Wykoff and Monserud (1987) for Douglas-fir. Again, use of site index did not improve the accuracy of the predictions.

Height increment has, from the inception of the Stand Prognosis Model, relied on habitat type (Stage 1975). The original model for trees greater than 5 inches d.b.h. was based on an allometric relation between height and diameter. In this model, habitat type affects both the allometric constant describing bole taper, and the constant setting the overall growth rate. However, as experience with the model accumulated, we saw that further improvement would come from adding a habitat type effect modifying the curve shape. The effect of this change was to reduce the height increment of tall trees on the warm-dry sites more than on the cold-moist sites (Wykoff and others 1982).

The submodel for height growth of trees less than 5 inches d.b.h. also relies on habitat type. Habitat types are grouped into as many as six classes according to similarity in submodel coefficients. The makeup of the classes also differs for each species.

Mortality

Mortality is strongly related to tree vigor, which in turn, is related to rates of increment. Therefore, all the factors that influence increment also influence mortality. Habitat types have been cited as a major factor in the accretion component of the Stand Prognosis Model, so it is no surprise that they also influence mortality. However, the actual data used to calibrate the model came from a limited range of habitat types (Hamilton 1986), which are among the most productive in the Inland Empire. Hence, the problem is to extrapolate in a reasonable way, based on theory, to other habitats which are less productive. The details of the procedure described by Hamilton (in preparation) rely on estimates of potential diameter growth rates and carrying capacity. Both of these variables depend on habitat types--the former through the diameter increment model described previously (tables 1 and 2), and the latter on estimates of basal area carrying capacity contained in the documentation of sample plots used in developing the classification of habitat types (Pfister and others 1977).

Net Productivity

Effects of habitat types on the components of the Stand Prognosis Model are so intertwined that demonstration of net effects on productivity is difficult to illustrate. Habitat types do not occur independently of the other factors of the site such as elevation, slope, aspect, and physiographic and geographic location. Therefore, illustrations prepared by holding all other factors constant and varying only habitat type will understate differences in productivity. However, by simulating plantations having different survival rates, the understatement can be reduced. Figure 1 shows simulated development of total cubic foot production and top-height for Douglas-fir planted at 500 trees per acre. Five-year survival is postulated at 90 percent on the *Tsuga* and *Abies grandis* habitats and 70 percent on the *Pseudotsuga* and *Abies lasiocarpa* habitats.

Validation of Effects

Comparison of actual growth records with simulations of expected growth is the final test of how well habitat types serve, in concert with other physical site factors, as a basis for yield forecasting. Because the Stand Prognosis Model does not use site index, bias in estimating heights of the 40 trees of largest diameter in the stand might vary with site index. Figure 2, based on 102 remeasured plots with an average duration of 39 years, shows that the estimates are not correlated with site index. Likewise, deviations in basal area are not correlated ($r = -0.049$) with site index.

REQUIREMENTS OF LAND CLASSIFICATIONS FOR GROWTH MODELING

Experience with using the habitat type classification in the Stand Prognosis Model, and in turn, using the estimates for land management planning suggests four criteria to be met.

1. Complete classification of all lands in a planning unit such as a National Forest should be feasible. This requirement implies that classification should be possible, using objectively definable criteria, by inventory crews given reasonable training.

2. Units should be mappable at resolutions of 2 to 10 acres per unit. In rough terrain, larger minimum sizes might imply inclusions of habitats having very different growth characteristics. Accommodating variation within units substantially increases the complexity of the growth and yield estimation system to be applied.

3. Classification should not change with stage of succession. In other words, seral classes would only be useful if they are seral to a single class of potential vegetation. This requirement avoids the indeterminacy that would result if a class assigned to the stand at time of inventory could evolve into two or more climax classes that might differ in their growth coefficients.

4. New systems of classification should evolve conservatively from their predecessors. To develop a growth and yield model based upon a

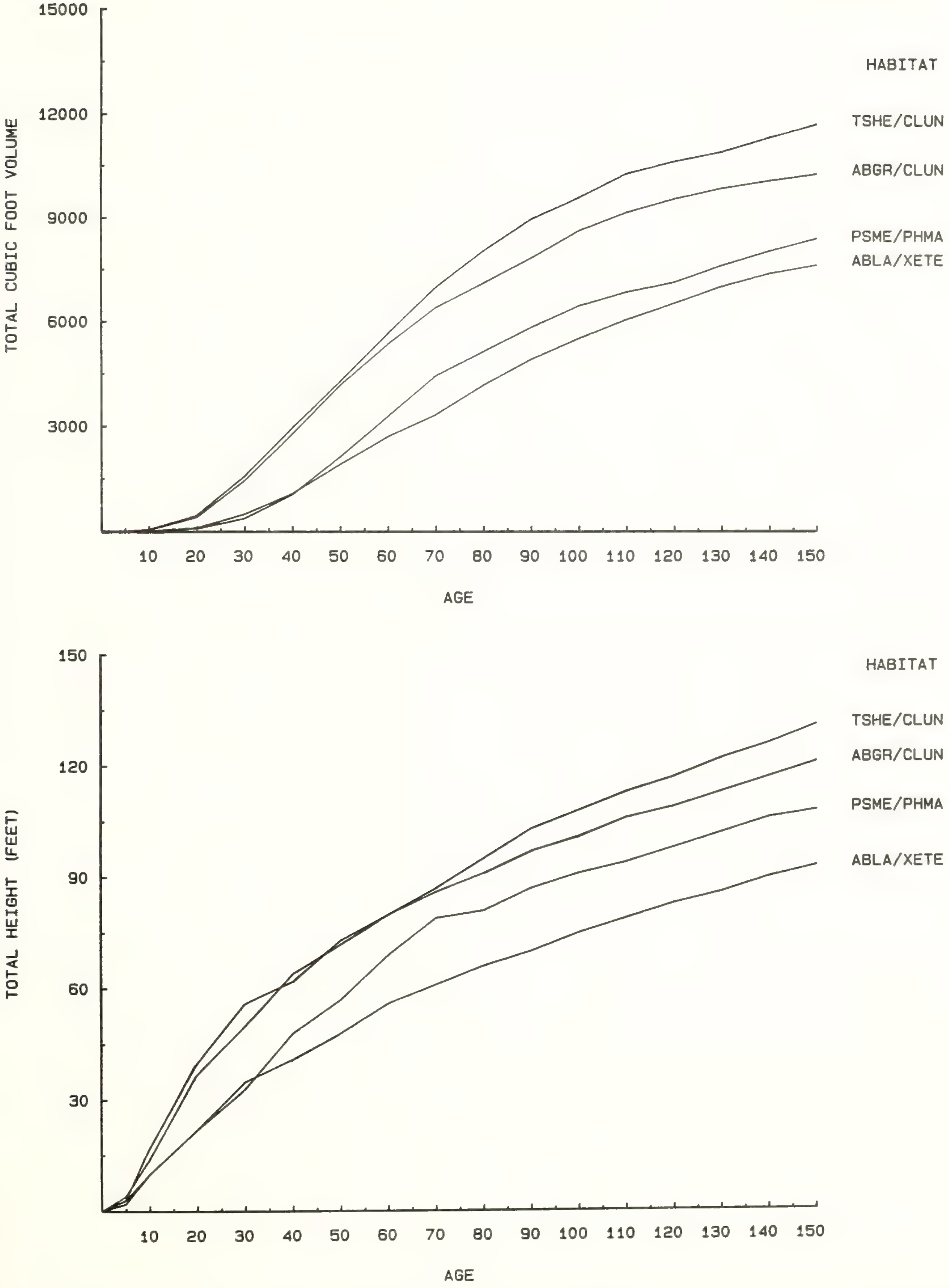

Figure 1--Predicted development of total cubic-foot volume and top height for four habitat types planted with 500 Douglas-fir trees per acre.

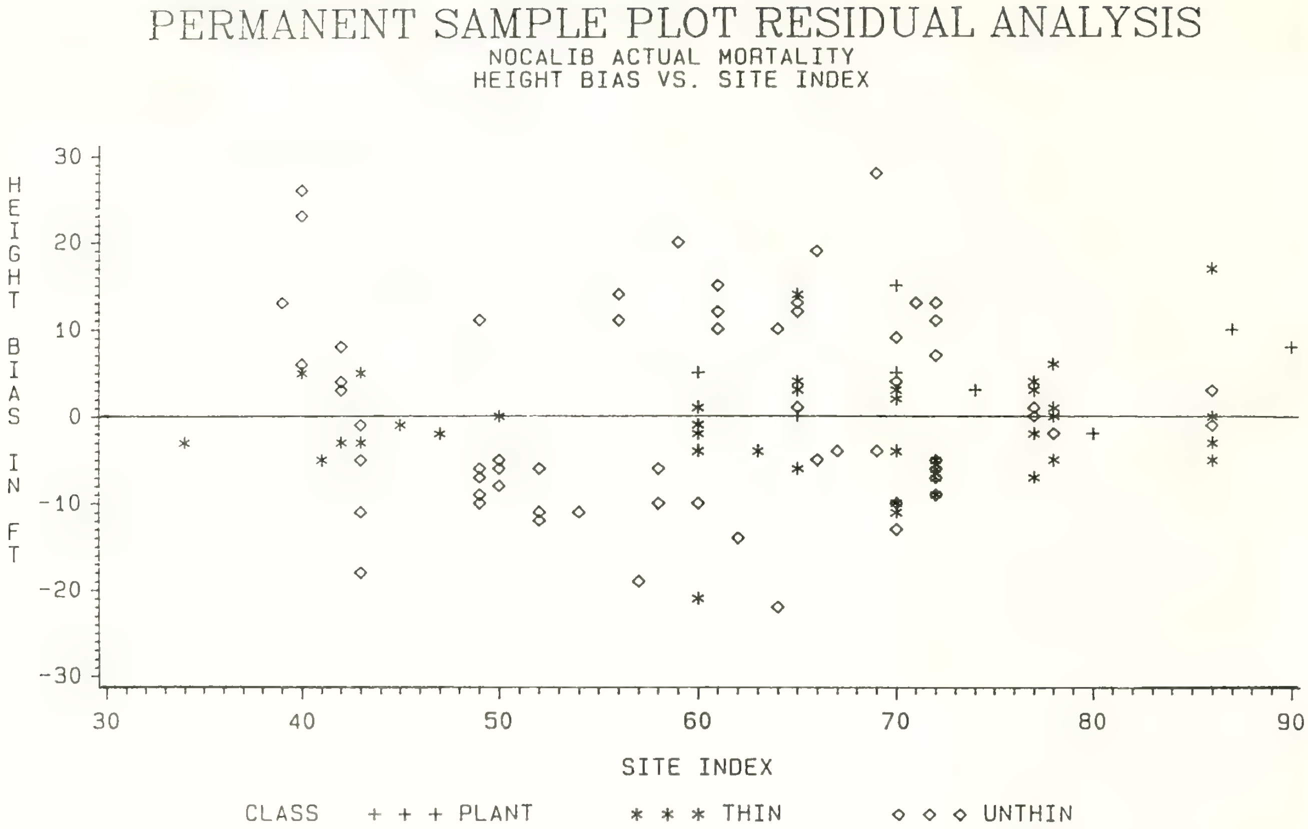

Figure 2--Differences between model predictions and observed values of stand top height (40 largest d.b.h./acre) versus site index, based on 102 plots in the Abies grandis-Tsuga heterophylla-Thuja plicata series. Vertical axis is observed values minus model predictions.

particular classification system requires time and substantial investment. In turn, application of the model requires that inventory data be classified to the same standards used in calibrating the growth relations. Hence, it is important that refinements be built upon the existing classification by dividing existing classes. In this way, the relations developed with the former system can be used while new data are accumulated for the revised system.

If these criteria are met, land classification based on vegetation provides a useful ecological foundation for estimating the dynamics of stand establishment, growth, and response to management.

REFERENCES

Corns, I. G. W; Pluth, D. J. 1984. Vegetational indicators as independent variables in forest growth prediction in west-central Alberta, Canada. Forest Ecology and Management. 9: 13-25.

Daubenmire, R. 1961. Vegetative indicators of rate of height growth in ponderosa pine. Forest Science. 7(1): 24-34.

Deitschman, Glenn H; Green, Alan W. 1965. Relations between western white pine site index and tree height of several associated species. Res. Pap. INT-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 28 p.

Etter, H. 1949. Uber die Ertragsfahigkeit vershiedener standortstypen. Mitteilungen der Schweizerishen Anstalt für das Forstliche Versuchswesen. 26(1): 91-152.

Ferguson, Dennis E.; Stage, Albert R.; Boyd, Raymond J. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. Forest Science Monograph 26. 41 p.

Gagnon, J. D.; MacArthur J. D. 1959. Ground vegetation as an index of site quality in white spruce plantations. Tech. Note 70. Canada Department of Northern Affairs and National Resources, Forestry Branch, Forestry Research Division. 12 p.

Hall, Frederick C. 1983. Growth basal area: a field method for appraising forest site potential for stockability. Canadian Journal of Forest Research. 13(1): 70-77.

Hamilton, David A. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. Forest Science. 32(4): 989-1000.

Hamilton, David A. [In preparation]. Spiffy little things: Expanding the limits of applicability of a mortality model. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory.

Hatch, Charles R. 1980. Modeling tree crown size using inventory data. In: Growth of single trees and development of stand; Mitteilungen der Forstlichen Bundesversuchsanstalt Wein. 130: 93-97.

Hodgkins, E. J. 1961. Estimating site index for longleaf pine through quantitative evaluation of associated vegetation. Proceedings, Washington, DC: Society of American Foresters. 28-32. 10 refs.

MacLean, Colin D.; Bolsinger, Charles L. 1973a. Estimating Dunning's site index from plant indicators. Res. Note PNW-197. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

MacLean, Colin D.; Bolsinger, Charles L. 1973b. Estimating productivity on sites with a low stocking capacity. Res. Pap. PNW-152. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Monserud, Robert A. 1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat type. Forest Science. 30(4): 943-965.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Roe, Arthur L. 1967. Productivity indicators in western larch forests. Res. Note INT-59. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Stage, Albert R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Stage, Albert R. 1975. Prediction of height increment for models of forest growth. Res. Pap. INT-164. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20 p.

Stage, Albert R. 1976. An expression for the effect of aspect, slope, and habitat type on tree growth. Forest Science. 22(4): 457-460.

Stage, Albert R. 1981. Use of self-calibration procedures to adjust general regional yield models to local conditions. In: Nishizawa, Masahisa, ed. Proceedings of forest resource inventory, growth models, management planning, and remote sensing; IUFRO World Congress; 1981 September 6-12; Kyoto, Japan. Kyoto, Japan: Niigata University Faculty of Agriculture, Laboratory of Forest Mensuration: 365-375.

Stanek, Walter. 1966. Relative quality of the major forest associations of the southern B.C. interior for growth of lodgepole pine, Engelmann spruce, Douglas-fir and alpine fir. Forestry Chronicle. 42(3): 306-313.

Westveld, Marinus. 1951. Vegetation mapping as a guide to better silviculture. Ecology. 32: 508-517.

Westveld, Marinus. 1952. A method of evaluating forest site quality from soil, forest cover, and indicator plants. Sta. Pap. 48. Upper Darby [Broomall], PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p. mimeo.

Westveld, Marinus. 1954. Use of plant indicators as an index to site quality. Sta. Pap. 69. Upper Darby [Broomall], PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Wykoff, William R. 1983. Predicting basal area increment for individual northern Rocky Mountain conifers. Mitteilungen der Forstlichen Bundesversuchsanstalt Wien. 147: 127-143.

Wykoff, William R. 1986. Supplement to the user's guide for the Stand Prognosis Model-Version 5.0. Gen. Tech. Rep. INT-208. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 36 p.

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Wykoff, William R.; Monserud, Robert A. (In press). Representing site quality in increment models: a comparison of methods. Presented at the IUFRO Forest growth modelling and prediction conference, 1987 August 23-27; Minneapolis, MN. 8 p.

INFLUENCE OF HABITAT TYPES ON FOREST PESTS OF THE NORTHERN ROCKY MOUNTAINS

Clinton E. Carlson

ABSTRACT: Major pests of Northern Rocky Mountain forests are affected by environmental conditions and vegetation depicted by habitat types (h.t.), but the interactions are weakly understood. Mountain pine beetle activity is limited in high-elevation PICO and ABLA h.t.'s where weather is very cold and moist, but is high in midelevation ABLA and PSME types where weather is more moderate. Western spruce budworm is most active on dry, warm PSME and ABGR h.t.'s, and similar to the beetle, is least active in the cold, wet ABLA types. Armillaria spp. occur most frequently in the productive ABGR, THPL, and TSHE h.t.'s but cause most damage in the poorer PSME and ABGR types. Susceptibility (probability of occurrence) and vulnerability (probability of damage) to all three pests seem to depend on relative shade tolerance of the host species. In general, when more than one host species is present, the most shade-tolerant ones, or the indicated climax, will be most susceptible and vulnerable to the pest. But when only one host species is present, and it is seral--such as lodgepole pine on ABLA h.t.s'--it may be extensively exploited by the pest. Multiple-use values are usually enhanced when forest management is structured to favor the seral species.

INTRODUCTION

Classification of forest sites using the habitat type system is well accepted and used extensively throughout much of the Western United States. This ecologically based system gives users a common basis from which to discuss proposed management activities affecting forest resources (Pfister and Arno 1980). Habitat types differ in climate, soils, and topography. These basic site differences, combined with disturbances such as fire, significantly influence succession and seral plant communities (Arno and others 1985). Forest pest activity is dependent on presence of a susceptible food base and favorable environmental conditions. Successional stage of the plant community, climate, and weather influence substrate susceptibility, ultimately affecting the pest. Knowing how the ecological factors associated with habitat types interact with forest insects and diseases would help land managers deal with these pests. The purpose of this paper is to synthesize current information concerning relations between habitat type and three major forest pests of the Northern Rocky Mountains--western spruce budworm (Choristoneura occidentalis Freeman), mountain pine beetle (Dendroctonus ponderosae Hopk.), and Armillaria spp. root disease. In this paper, influence of habitat type on pests means the combined influence of underlying environmental factors associated with habitat type.

MOUNTAIN PINE BEETLE

Mountain pine beetle is found throughout the range of its primary host, lodgepole pine (Pinus contorta ssp. latifolia). The range includes many habitat types. From an ecological perspective, it is meaningful to consider the habitats where lodgepole occurs to understand the wide amplitude of the beetle. According to Pfister and Cole (1985), lodgepole is minor seral in 10 habitat types, dominant seral in 26, and persistent/climax in 6 (table 1). Abbreviations of habitat type names follow Pfister and others (1977).

On warm, dry habitat types, where lodgepole is minor seral, average annual precipitation is about 18 inches and mean July temperature is about 62 °F. Where the species attains its greatest importance (dominant seral), and where mountain pine beetle is a significant problem, precipitation averages around 40 inches annually and mean July temperature is about 60 °F (Pfister and others 1977). Clearly, lodgepole pine and the beetle have broad ecological amplitudes in the Northern Rockies. But the beetle is subjected to a narrower range of specific conditions because the tree acts as a buffer between the insect and the outside environment.

Although the ecological amplitude of the beetle is known, the specific influence of habitat type on the insect has received little attention and is not well understood. Evidence is conflicting and difficult to interpret. Roe and Amman (1970) reported that current beetle activity, measured by the number of stands infested, was highest in ABLA/PAMY habitat types in northwestern Wyoming and southeastern Idaho--92 percent of the stands observed were infested. Activity was intermediate in PSME/CARU types--64 percent--and lowest in ABLA/VASC types where only 44 percent of the

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Clinton E. Carlson is Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Table 1--Ecological role of lodgepole pine in the Northern Rocky Mountains (modified from Pfister and Cole 1985)

	Habitat type			
Successional role	Warm, dry	>>>>>>>>>>>>>>>>>>>>>>>>		Cold, moist
Minor seral	PSME/SYAL	ABGR/CLUN		ABLA/LUHI
	PSME/PHMA	ABGR/LIBO		TSME/MEFE
	ABLA/CLPS	TSHE/CLUN		TSME/LUHI
		THPL/CLUN		
Dominant seral	PSME/LIBO	PICEA/PHMA	ABGR/ZETE	ABLA/CAGE
	PSME/CARU	ABLA/CLUN	PSME/VAGL	ABLA/PIAL/VASC
	ABLA/CARU	PSME/VACA	ABLA/XETE	ABLA/CACA
		PICEA/CLUN	PSME/JUCO	ABLA/VASC
		PICEA/GATR		ABLA/MEFE
		PICEA/LIBO		TSME/XETE
		PICEA/SMST		
		PICEA/VACA		
		ABLA/VAGL		
		ABLA/ALSI		
		ABLA/ARCO		
		ABLA/GATR		
		ABLA/LIBO		
Persistent/climax			PICO/VACA	ABLA/VACA
			PICO/LIBO	PICO/PUTR
			PICO/CARU	
			PICO/VASC	

stands were infested. But infestation intensity was about the same among habitat types. In a study conducted on the Gallatin National Forest (NF) in Montana, beetle activity was measured as percent lodgepole mortality expressed in basal area/acre, in trees greater than or equal to 8 inches d.b.h. (McGregor 1978). In that study, McGregor purported to show an effect of habitat type on beetle activity. On a relatively dry elevational gradient, most activity was found in the PSME/CARU-CARU and ABLA/CARU habitat types (42 percent mortality in each type). Slightly lower mortality (40 percent) was observed in the ABLA/ VASC-CARU type, and least activity (25 percent) was noted in the ABLA/VASC-VASC type. On a moist gradient, most beetle-caused mortality was found in the PICEA/LIBO type and least in the ABLA/ALSI type (table 2).

Table 2--Mountain pine beetle-caused tree mortality, habitat type, lodgepole pine basal area, and elevation on the Gallatin NF (from McGregor 1978)

Habitat type	Slope environment	LPP basal area in stand	Elevation	Mortality
		(%)	(Ft)	(%)
PSME/CARU	Dry	48	6,000	42
ABLA/CARU	Dry	61	--	42
ABLA/VASC-CARU	Dry	81	--	40
ABLA/VASC-VASC	Dry	83	8,000	25
PICEA/LIBO	Moist	25	5,800	40
ABLA/LIBO	Moist	61	--	40
ABLA/VAGL	Moist	71	--	20
ABLA/ALSI	Moist	58	8,000	13

McGregor's (1978) analysis was confounded by changing basal area of lodgepole and elevation of the stands. Thus, the effect of habitat type on the beetle is not predictable based on that work. One can only state that in those stands at that time, mortality due to the beetle was at the observed levels.

Analyses of more recent data from the Gallatin NF indicated that habitat type was associated with percentage of trees killed and cubic volume lost due to beetle activity (Cole and McGregor 1983; Cole and others 1985). Bivariate models were constructed, using percentage of trees killed as the dependent variable and time (years) as the independent variable. Models were computed on a stand-by-stand basis where each stand had a unique habitat type. Models for several stands were plotted on each graph, and the differences between models were attributed to habitat type. The plotted regression lines (Cole and McGregor 1983), however, did not match the models presented. The models were developed with mortality data from only 2 years--the first and last--10 years hence. Yet the time axis (X) on the graphs of the regression models included 11 years. Gayle Yamasaki, who did the original analyses, clarified the problem. If the quantity (1 +X/10) is substituted for X in the models, the models match the plotted equations (Yamasaki 1988). One further correction in the graphs--the ordinates should be labeled "proportion of trees lost to beetles" instead of "percent of trees lost to beetles." Because only two points were used in calculation of the regression models, it is difficult to know whether the relations are linear or curvilinear.

It also is difficult to recognize an effect of habitat type on beetle activity based on the Cole and McGregor (1983) models. The models were very dissimilar for a given habitat type from two different (but geographically close) areas. The model for ABLA/CARU at Hebgen was Y = 0.113 + 0.044X, whereas the ABLA/CARU at Madison was -0.185 + 0.209X (Cole and McGregor 1983). The slopes and intercepts are very different and there appears to be as much variation within h.t.'s as between. This is not surprising--the effects of slope, aspect, elevation, soils, tree size, and stand age were not considered in the analyses. No statistics, such as the coefficient of determination, error mean square, confidence intervals, or analyses of variance, were given so it is impossible for the reader to evaluate goodness of fit for any of their models. Each model represents a case history for each stand sampled. Differences between stands may or may not be due to habitat type. Perhaps a reanalysis of their data, using multivariate or multiple regression techniques, would be enlightening.

Future studies of relations between mountain pine beetle and its environment should, as Cole (1985) aptly suggested, be couched in an ecological framework. All variables suspected of influencing the insect should be measured at each sampling point. These include, but are not limited to, soils, slope, aspect, elevation, habitat type, successional stage, amount of host and nonhost, host size, age, vigor, stand density, and recent weather.

Seral status of host species may also be important in beetle dynamics. Mountain pine beetle caused extensive mortality in pure ponderosa pine (Pinus ponderosa ssp. ponderosa Dougl.) stands about 8 to 10 inches d.b.h. on ponderosa pine habitat types south of Bend, OR. In nearby lodgepole pine habitat types, however, where ponderosa was seral and mixed with climax lodgepole, the lodgepole was heavily damaged by the beetle, yet the ponderosa was seldom affected (Carlson 1987). Where both species are seral, mortality has been about equal between them (Gibson 1987). Multivariate analyses may elucidate pertinent relations between beetle activity and these variables. At present, however, little definitive work has been accomplished concerning the influence of habitat type on mountain pine beetle. This statement is supported in that current models simulating beetle dynamics do not use habitat type as a predictor variable (Raffa and Berryman 1986; Schenk and others 1980).

WESTERN SPRUCE BUDWORM

Like mountain pine beetle, western spruce budworm has a broad ecological amplitude in the Northern Rockies (table 3). Budworm occurs in many habitat types in six forest climax series ranging from the warm, dry PSME to the cool, moist ABLA. The insect is found from elevations as low as 2,000 feet MSL (mean sea level) to higher than 8,500 feet, and occurs on all slopes and aspects.

Table 3--Occurrence of western spruce budworm in Montana by forest climax series (from Carlson and others 1985)

Forest climax series	Elevational range	Mean annual precipitation	Mean July temperature
	(Ft)	(In.)	(°F)
PSME	2,000-7,800	17-20	60-66
PICEA	2,900-8,600	23-26	56-61
ABGR THPL TSHE	2,000-5,000	30-34	64
ABLA (lower sub-alpine)	3,200-8,500	21-53	57-64

Budworm is seldom found in the upper ABLA habitat types where the weather is too cold and wet. In other habitat types, stand susceptibility to the insect varies with several factors, including regional climate, intrinsic site climate, species composition, host/nonhost density, stand structure, stand vigor, stand maturity, and continuity of surrounding host type (Carlson and others 1985). Intrinsic site climate (the integration of slope, aspect, elevation, and general climate) was indexed by habitat type in rating stand susceptibility to budworm (Wulf and Carlson 1985) as shown in table 4. The index reflects the knowledge that warm, dry habitats are most favorable for budworm (Wulf and Cates 1987).

Table 4--Relative importance of habitat type in stand susceptibility to budworm (from Wulf and Carlson 1985)

Habitat group	Index value
Cold ABLA, timberline types	0
Cool, moist PICEA; cool, moist ABLA types	0.6
Warm, moist ABGR; THPL, TSHE; warm, moist ABLA types	1.0
Cold PSME; cold ABGR; cool, dry PICEA; cool, dry ABLA types	1.2
Moist ABGR; warm, moist PICEA; warm, moist ABLA types	1.3
Mesic PSME; dry ABGR; warm mesic PICEA; warm, dry ABLA types	1.4
Warm, dry PSME types	1.5

Budworm feeding activity varies significantly with habitat type (Carlson and others 1982). Regression analyses relating budworm-induced radial growth depression to elevation, proportion host basal area, slope, aspect, and habitat type suggested that growth reduction was highest on south-facing steep aspects in dry PSME and ABGR habitat types. The influence of budworm on natural regeneration following harvest also is dependent on habitat type. On dry south-facing PSME habitats where slope was 40 percent, stocking probability was only 0.12 (fig. 1). But on moist ABLA habitats with slopes of 60 percent, where defoliation of the host species was similar to that observed on the PSME types, stocking probability was about 0.60 (Carlson and others 1982). Poor regeneration on the PSME habitats was attributed to seed and cone depredation by budworm, fewer conifer species, and generally poorer environmental conditions for seedling germination and establishment. Finally, the influence of habitat type on budworm is strongly dependent on host presence and abundance. A ponderosa pine/western larch (Larix occidentalis Nutt.) seral community on a PSME habitat type obviously would not be susceptible to budworm, unlike a Douglas-fir sere. Even though larch is vulnerable to budworm (may be damaged), the species is not very susceptible (will not support the life cycle).

Host susceptibility is strongly influenced by habitat type. For example, Douglas-fir on a PSME habitat type is highly vulnerable to budworm. But when in a seral role, Douglas-fir is far less preferred by the insect. On ABGR and ABLA h.t.'s in central Idaho, grand fir (Abies grandis (Dougl.) Forbes) and subalpine fir (A. lasiocarpa (Hook.) Nutt.) were heavily defoliated; Douglas-fir was barely affected (fig. 2) (Carlson and others 1985; Wulf and Cates 1987). In reviewing aerial survey maps of defoliation and correlating them with forest cover type and habitat type, Sutherland (1983) noted that Douglas-fir was much less defoliated on ABGR and ABLA fir habitat types than where it was climax. In northeastern Oregon, where budworm was epidemic for 8 to 12 years, radial growth of Douglas-fir was less severely affected than that of grand fir or Engelmann spruce (Picea engelmannii Parry) on, presumably, grand fir habitat types (Williams 1966). Reasons for this changing susceptibility are unknown. Sutherland (1983) postulated that Douglas-fir in a seral role may be more vigorous and more able to resist insect attack. Another hypothesis is that volatile foliar compounds influence feeding preference. Small second-instar budworms are evenly dispersed in spring (Carlson and others in press). After being wind-dispersed the tiny larvae search for suitable feeding sites. The search may be chemically mediated--the larvae "sniff" for suitable food. If grand fir and subalpine fir, which are highly aromatic, release better or more appropriate chemical stimuli than Douglas-fir, the small larvae would tend to leave the Douglas-fir and would probably die. Larvae on the true firs likely would stay there, resulting in differential defoliation. In pure Douglas-fir stands, however, this hypothesized chemical gradient would not be present, and larvae would tend to stay put, resulting in more even defoliation. These are only hypotheses; mechanisms for the differential susceptibility of Douglas-fir to budworm among habitat types remain unknown.

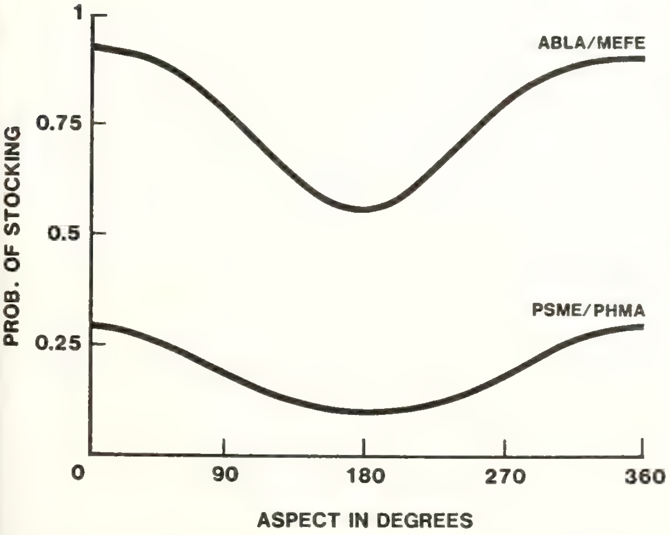

Figure 1--Influence of habitat type and aspect on probability of stocking in the Northern Rocky Mountains. Western spruce budworm contributed significantly to the low stocking in the PSME/PHMA h.t.'s.

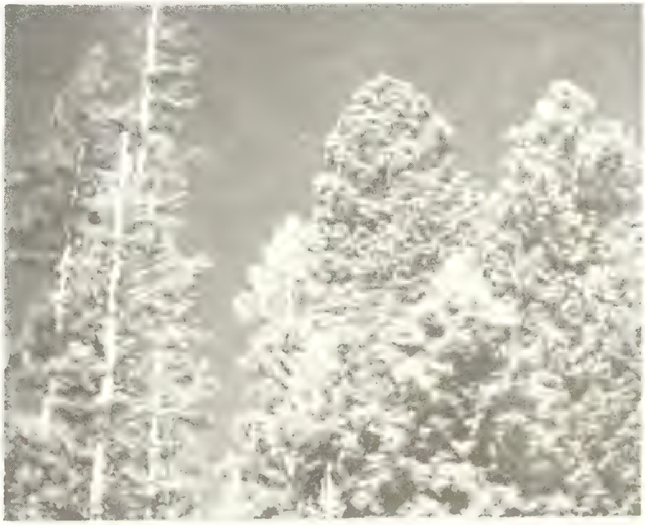

Figure 2--Effect of seral status of host species on vulnerability to budworm. On this ABGR h.t., grand firs, the climax species for the site, are extensively damaged by the insect; Douglas-firs, which are seral, are not affected.

ARMILLARIA ROOT DISEASE

Armillaria spp. are ubiquitous, causing root disease in forbs, shrubs, and broadleaf and conifer trees across a wide range of environments. It is a serious disease. James and others (1984) identified root disease centers on nearly 78,000 acres (1 percent of the total forested area), in seven Northern Rocky Mountain National Forests. Taxonomy of *Armillaria* spp. is in question. *Armillaria mellea* (Vahl. ex Fr.) Kummer was generally recognized as the causal organism until recently when other *Armillaria* species were suspected of causing disease (Wargo and Shaw 1985). In the Northern Rockies, plant pathologists hypothesize that the fungus, perhaps *A. ostoyae*, may function as a facultative pathogen, causing disease in trees already under stress (McDonald and others 1987a). Whatever the case, *Armillaria* is likely present in every habitat type of the Northern Rockies.

Habitat type apparently influences root disease. Williams and Marsden (1982) discovered that stands older than 100 years and stocked primarily with Douglas-fir and grand fir were more likely to have root disease centers (*Armillaria* and *Poria weirii*) when on PSME and ABGR habitat types than when on TSHE types (fig. 3). Other site and stand factors related to habitat type had a major influence on disease. Probability of disease increased with increasing age (up to 100 years), was highest on east to southeast aspects, and interacted with soils and aspect (Williams and Marsden 1982).

Recent work corroborates and extends the work of Williams and Marsden (1982). McDonald and others (1987a) randomly sampled 78 plots in the Northern Rocky Mountains and determined the incidence of pathogenic *Armillaria*. Proportion of plots with pathogenic *Armillaria* on conifer species decreased as habitat productivity increased. TSHE h.t.'s had the least amount of disease, followed by THPL, ABGR, PSME, and ABLA in increasing order of incidence. Disturbed plots on the highly productive types had more disease than undisturbed; the opposite was true for the least productive types. Furthermore, Douglas-fir, grand fir, subalpine fir, and Engelmann spruce were most susceptible when they were climax, not seral.

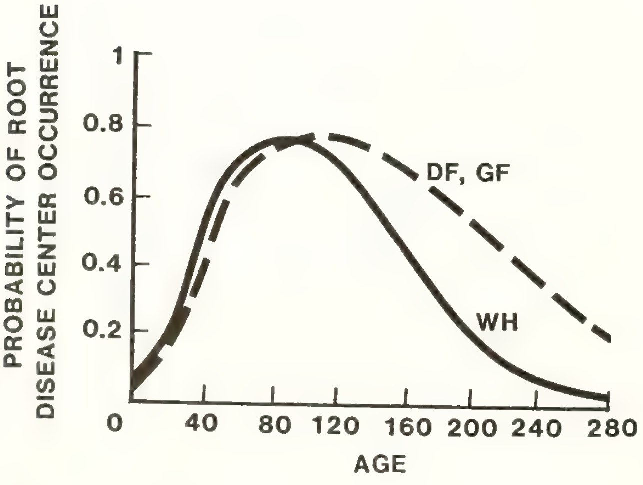

Figure 3--Influence of habitat type and stand age on root disease center occurrence. DF, GF, and WH mean PSME, ABGR, and TSHE h.t.'s, respectively (from Williams and Marsden 1982).

Assessing the general distribution of *Armillaria*, not just its pathogenic occurrence, resulted in different conclusions (McDonald and others 1987b). TSHE and THPL h.t.'s had the highest proportion of plots with the fungus, 0.93 and 1.00 respectively, but the least amount was found on the ABLA (0.42) and PSME (0.33) h.t.'s (table 5). In the general distribution, incidence of *Armillaria* was assessed on hardwoods and conifers on each plot. Pathogenic occurrence was assessed only on conifers. Thus, even though the fungus can be found just about anywhere in the forest, and in greatest frequency on good sites, expression of the disease is probably regulated by specific site and stand factors. Nutrient and moisture stress, likely affected in large part by habitat type, are hypotheses to be tested.

Table 5--Probability of general and pathogenic occurrence of *Armillaria* in the Northern Rocky Mountains (from McDonald and others 1987a and 1987b)

Habitat series	Probability of general occurrence	Probability of pathogenic occurrence
ABLA	0.42	0.53
PSME	.33	.67
ABGR	.79	.31
THPL	1.00	.20
TSHE	.93	.13

CONCLUSIONS

The influence of habitat type on forest pests, including mountain pine beetle, western spruce budworm, and *Armillaria* root disease, is not well understood, but we are beginning to see some relationships. Mountain pine beetle incidence seems not to be closely related to habitat type--other factors, such as elevation, slope, and aspect, seem to be more influential. Much of the work on the beetle has been done during epidemics, and the population momentum probably overrides many environmental influences. Study of endemic populations may reveal some of the more intricate relationships between the beetle and its environment. Budworm is active over a wide range of environmental conditions, but warm, dry PSME h.t.'s seem to be most favorable to this insect. *Armillaria* root disease also appears most damaging in drier habitats.

A common host-pest interaction may be hypothesized for all three pests discussed. When more than one host species is present, the pest is most active on the most shade-tolerant or the climax host. On ABGR and ABLA habitat types, budworm causes far more damage on grand fir and subalpine fir than on Douglas-fir. But on PSME h.t.'s, Douglas-fir is extensively defoliated. Similarly, on a given h.t., Armillaria root disease and mountain pine beetle apparently are most active on the climax species. This hypothesis needs to be tested. If it turns out to be true, then managing intensively for seral species should reduce pest activity over the long run.

Studies on the effect of habitat type on forest pests need to consider successional stage. Methods to classify successional stages are under development and will add a new and very important stabilizing variable to forest pest research (Arno and others 1985; Steele 1984). Studies designed to include successional stage, slope, elevation, aspect, and soils data within habitat types are needed to explain the high amount of variability observed to date. Once we have this level of knowledge, Vasechko's (1983) concepts on forest protection through ecological approaches may have a chance to succeed.

REFERENCES

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Carlson, Clinton E. 1987. Unpublished personal observations of a mountain pine beetle epidemic in south-central Oregon. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Missoula, MT.

Carlson, Clinton E.; McCaughey, Ward W.; Theroux, Leon J. [In press]. Relations among stand structure, dispersal of second-instar western spruce budworm, defoliation, and height growth of young conifers. Canadian Journal of Forest Research.

Carlson, C. E.; Schmidt, W. C.; Fellin, D. G.; Wulf, N. W. 1985. Silvicultural approaches to western spruce budworm management in the Northern U.S. Rocky Mountains. In: Sanders, C. J.; Stark, R. W.; Mullins, E. J.; Murphy, J., eds. Recent advances in spruce budworms research. Proceedings, CANUSA spruce budworms research symposium; 1984 September 16-20; Bangor, ME. Ottawa, ON: Environment Canada: Canadian Forestry Service and U.S. Department of Agriculture, Forest Service: 281-300.

Carlson, Clinton E.; Theroux, Leon J.; McCaughey, Ward W. 1982. The influence of silvicultural practices on the susceptibility and vulnerability of Northern Rocky Mountain forests to the western spruce budworm. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Missoula, MT. 55 p.

Cole, Dennis M. 1985. Occurrence of lodgepole pine stands according to habitat type and successional role. In: McGregor, Mark D.; Cole, Dennis M., eds. Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. Gen. Tech. Rep. INT-174. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 31-37.

Cole, Walter E.; McGregor, Mark D. 1983. Estimating the rate and amount of tree loss from mountain pine beetle infestations. Res. Pap. INT-318. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Cole, Walter, E.; Amman, Gene D.; Jensen, Chester E. 1985. Mountain pine beetle dynamics in lodgepole pine forests. Part III: sampling and modeling of mountain pine beetle populations. Gen. Tech. Rep. INT-188. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 46 p.

Gibson, Kenneth E. 1987. [Personal communication]. October. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Cooperative Forestry and Pest Management.

James, R. L.; Stewart, C. A.; Williams, R. E. 1984. Estimating root disease losses in Northern Rocky Mountain National Forests. Canadian Journal of Forest Research. 14: 652-655.

McDonald, Geral I.; Martin, Neil E.; Harvey, Alan E. 1987a. Armillaria in the Northern Rockies: pathogenicity and host susceptibility on pristine and disturbed sites. Res. Note INT-371. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 5 p.

McDonald, Geral I.; Martin, Neil E.; Harvey, Alan E. 1987b. Occurrence of Armillaria spp. in forests of the Northern Rocky Mountains. Res. Pap. INT-381. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p.

McGregor, Mark D. 1978. Management of mountain pine beetle in lodgepole pine stands in the Rocky Mountain area. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., eds. Theory and practice of mountain pine beetle management in lodgepole pine forests. Symposium proceedings; 1978 April 25-27; Pullman, WA. Pullman, WA: Washington State University: 129-139.

Pfister, Robert D.; Arno, Stephen F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26: 52-70.

Pfister, Robert D.; Cole, Dennis M. 1985. The host. In: McGregor, Mark D.; Cole, Dennis M., eds. Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. Gen. Tech. Rep. INT-174. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 7-28.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Raffa, Kenneth F.; Berryman, Alan A. 1986. A mechanistic computer model of mountain pine beetle populations interacting with lodgepole pine stands and its implications for forest managers. Forest Science. 32: 789-805.

Roe, Arthur L.; Amman, Gene D. 1970. The mountain pine beetle in lodgepole pine forests. Res. Pap. INT-71. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Schenk, J. A.; Mahoney, R. L.; Moore, J. A.; Adams, D. L. 1980. A model for hazard rating lodgepole pine stands for mortality by mountain pine beetle. Forest Ecology and Management. 3: 57-68.

Steele, Robert. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

Sutherland, Mary Gayle. 1983. Relationship of site and stand characteristics to outbreaks by western spruce budworm in the Bitterroot National Forest. Pullman, WA: Washington State University. 54 p. Thesis.

Vasechko, G. I. 1983. An ecological approach to forest protection. Forest Ecology and Management. 5: 133-168.

Wargo, Philip M.; Shaw, Charles G., III. 1985. Armillaria root rot: the puzzle is being solved. Plant Disease. 69: 826-832.

Williams, Carroll B., Jr. 1966. Differential effects of the 1944-56 spruce budworm outbreak in eastern Oregon. Res. Pap. PNW-33. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Williams, Ralph E.; Marsden, Michael A. 1982. Modelling probability of root disease center occurrence in northern Idaho forests. Canadian Journal of Forest Research. 12: 876-882.

Wulf, N. William; Carlson, Clinton E. 1985. Generalized indexing model. In: Brookes, Martha H.; Colbert, J. J.; Mitchell, Russel G.; Stark, R. W., tech. coords. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service: 51-54.

Wulf, N. William; Cates, Rex G. 1987. Site and stand characteristics. In: Brookes, Martha H.; Campbell, Robert W.; Colbert J. J.; Mitchell, Russel G.; Stark, R. W., tech. coords. Western spruce budworm. Tech. Bull. 1694. Washington, DC: U.S. Department of Agriculture, Forest Service: 89-115.

Yamasaki, G. 1988. [Personal communication]. January 25-26. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

SOIL-HABITAT TYPE RELATIONSHIPS:

A THEORETICAL MODEL

Kenneth E. Neiman, Jr. and Minoru Hironaka

ABSTRACT: Studies of site factors have led to theories that both soil development and plant community composition are functions of climate, parent material, relief, and potential organisms interacting over time. This paper presents a theoretical model based on the premise that one habitat type can be correlated with many soils, but an individual soil is only related to a single habitat type. This model creates a means by which similar seral communities can be assigned to their proper habitat type and more accurately positioned within successional development pathways.

INTRODUCTION

Vegetation-based land classification systems (such as Daubenmire and Daubenmire 1968; Pfister and others 1977; Hironaka and others 1983; Johnson and Simon 1987; and others) depend on knowledge of existing floristics for identification of taxonomic plant associations. On forested lands that have not been severely disturbed, habitat type identification can be accomplished with relative ease. But as more land is subjected to the severe disturbances of even-aged management prescriptions, future habitat type identification will require extrapolation from highly disturbed seral plant communities which often have little floristic similarity to the climax community. As severe disturbances increase so does the need to extrapolate habitat type identification from seral community types by using both biotic and abiotic site characteristics.

Hypothetically, all sites with similar vegetation, climate, site characteristics, parent material, and age should have soils with similar horizonations and chemical compositions (Jenny 1941). Due to environmental factor compensation and physiological plasticity of species, we find many sites that have similar vegetation composition, although these sites do not have similar physical environments. Consequently, we find the same climax plant association occurring on both north and south aspects or over highly different parent materials. Thus, different soils often develop beneath similar vegetation communities.

This paper expands on a conceptual model of secondary succession developed by Huschle and Hironaka (1980) and the theoretical teachings about plant community-soil relationships of Drs. Min Hironaka and Maynard Fosberg at the University of Idaho, Moscow. Throughout this paper, habitat type to the phase level, plant association, and climax plant community are used interchangeably. The basic premise is that one habitat type phase can occur over more than one soil, but the converse is not true. Within a habitat type phase each set of functional soil forming factors will develop a soil specific to that set of environmental conditions. Therefore, a unique set of soils can be correlated with individual habitat types and phases of habitat types. The soils associated with one habitat type phase often show variation ranging from slight changes of characteristics within a soil series or series-phase taxonomic unit to possible changes of more than one Order. But most important to this model, one identifiable soil unit will only support one specific habitat type phase.

DISCUSSION

Both internal and external sets of independent factors affect the development of individuals in most all physical and biological systems. Nowhere is this more observable than in the wide variety of natural plant communities and soil horizonations. Jenny (1941) describes a set of five factors that characterize the formative elements for all soil development. Major (1951) felt that plant community composition on any given site is a similar function of the same five factors. These factors are: climate, in the sense of regional macroclimate; parent material, the basement rock or depositional material from which the soil originates; relief (topography), the slope, aspect, elevation, landform, and related ground water conditions; organisms, the micro- and macro-organisms of plant and animal species potentially available for site occupancy; and time, the zero point starting from the initiation of soil formation or since major disturbance to existing conditions. Jenny (1958, 1980) further elaborates on this concept with particular reference to the effects of plants as pedogenic (soil forming) factors. The "potential biota" for a site is independent of all other factors, but due to variation in physiological tolerance of species to microclimatic changes caused by natural

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Kenneth E. Neiman, Jr., is Forest Ecologist, Resource Analysis and Management, Seattle, WA; Minoru Hironaka is Professor of Range Sciences, University of Idaho, Moscow, ID.

successional processes, only a limited number of the potential species will successfully persist on a given site. Unlike plant community successional concepts, we consider soil as having only primary successional development.

Many taxonomies have been developed for both plant communities and soils, but little direct analysis of their interrelationships has been reported. A problem for analyses of this kind is that soil and plant community classifications are both artificial systems, developed for different purposes, and are not compatible in either scale or units. A second problem often encountered in soil-vegetation analysis has been the lack of sufficient data to allow for proper stratification of samples collected from widely varying geographic locations, parent materials, climatic regimes and histories, and disturbance histories. Daubenmire (1970) recognized the importance of soil factors to vegetation and strongly stated "those soil properties suspected of playing important roles in vegetation differentiation are not among the characteristics emphasized in soil classification." Soil moisture and temperature regimes, aeration, and nutrients are the important attributes for vegetation (Loucks 1962, Daubenmire 1970). Also, vegetation responds to both long-term and short-term environmental changes (Daubenmire 1956), particularly extremes of temperature and moisture, whereas, climatic pulses tend to have only a minor effect on soil formation processes. Although they are often evaluated during field data collection by the soil scientist, none of these attributes considered important for vegetation are adequately assessed for forested environments by current soil taxonomic systems.

The trend in recent studies has been to investigate the relationship of individual or multiple soil characteristics to differing plant communities. Hann (1982) qualitatively described a number of soil-parent material-environmental conditions in western Montana which related very well to differing successional communities and specific habitat types. Sondheim and Klinka (1983) identified significant correlations between soil characteristic-site physiographic attributes and plant associations. Tisdale and Bramble-Brodahl (1983) conducted a statistically based, intensive study of vegetation communities and soil along the Salmon and Snake Rivers. They concluded that a satisfactory set of abiotic soil-site variables could be developed to identify the habitat type of a site even though only seral vegetation might be present. Neiman (1986) identified differentiating relationships between physical soil characteristics and six highly similar habitat types of northern Idaho.

It is necessary in the following thought process to divorce oneself from Soil Taxonomy (USDA SCS 1975) and its structured soil classification units. Do not expect the soil variation to be adequately described by taxonomic units such as series or series-phase. In some instances, these units are not defined tightly enough for usage in this context, and in many more instances, the terms are being interpreted differently by various groups of soil professionals. The characteristics which separate one habitat type specific soil unit from another may not be significant variables in soil taxonomic classifications. Or a finer level of group subdivision may be required than is currently identified by soil taxonomies. Problems with previous research in this subject area have been the selection of site and soil characteristics to be analyzed based on assumptions of their ecological significance, and, more often, the use of data sets from widely varying geographic and geologic origins. One must suppress, for the time being, the desire to attach ecological meaning to relationships unearthed by research and analysis.

An identifiable soil unit is defined herein as a polypedon (group of pedons) which has very similar physical and chemical characteristics throughout its genetic horizonation. A change in one or more of its characteristics must be accompanied by a change in habitat type phase. At this point in the development of the theoretical model, it is unknown how similar the variables must be in order to have only one habitat type phase supported by one soil unit. It is expected that the discriminating soil characteristic(s) and its amount of variation will change under various environmental conditions as found by Hann (1982) and Neiman (1986). The search must be for individual or reduced sets of physical or chemical soil characteristics that correlate with a habitat type phase. Large data bases will be required to demonstrate correlation rather than merely extraneous random data structure.

Huschle and Hironaka's cone model (1980) conceptualizes all above ground environments occupied by a single habitat type phase. The cone is subdivided from apex to base into climax plant community and all potential secondary successional communities, with early pioneer species communities dominating the base layer of the cone. In figure 1, the successional pathway visible on the face of the cone theoretically proceeds from five pioneer community types to three early-mid seral community types which reduce to two late seral types before returning to the climax association.

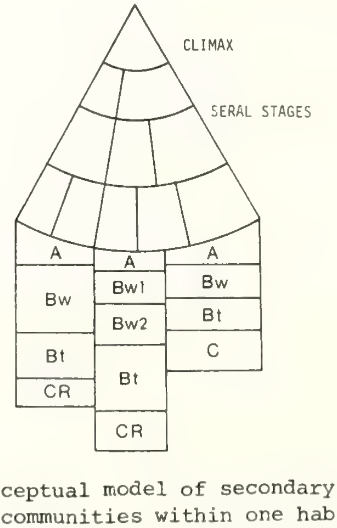

Figure 1--Conceptual model of secondary successional plant communities within one habitat type-phase and their relationship to habitat type-phase specific soil units.

If we then superimpose the various soils found within a single habitat type phase as a layer below the cone, we have a means of visualizing a variety of above and below ground environments. But the hypothesis remains that for each habitat type phase there exists a unique set of identifiable soils. Support for this theoretical change in soils with a change in habitat type phase can be found in the studies of Hann (1982), Sondheim and Klinka (1983), Tisdale and Bramble-Brodahl (1983), and Neiman (1986).

When we introduce a second cone model from an ecologically similar habitat type phase, we can show that many plant community types, particularly the early seral communities, are not unique to a habitat type. This is shown by community types 4 and 5 occurring in both habitat types I and II (fig. 2). The assumption often made is that highly similar plant communities have equivalent environments. And, although the equivalency of biological environments for plant reproduction and establishment cannot be disputed, factor compensation and species plasticity make allowances for what often are dissimilar physical environments.

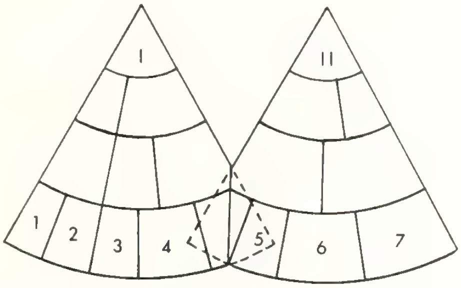

Figure 2--Conceptual model of seral plant communities in two closely associated habitat type-phases. The overlapped cones represent seral communities (4 and 5) common to both climax associations.

Our hypothesis can now be expanded to include specific seral communities that consistently relate to only one or a reduced set of habitat type phase specific soil units (fig. 3). Also, hypothetically, one seral community and one successional development pathway (sere) may relate to only one soil unit, but we have only anecdotal evidence for this at present. The distinctive power of this model is that although seral plant communities of closely associated habitat types are often very similar in both species composition and physiognomy, they will always occupy different soil units and can therefore be identified as communities having different climax endpoints.

Until further research can be undertaken, it is assumed that one cone model will be required for each habitat type phase and disturbance history. We also speculate that a cone for each vegetative layer (trees, shrubs, and forbs) as described by Steele (1984) would greatly increase the predictive accuracy of the model. Within each cone model, the seral communities and successional development pathways may change with variations in kind and/or intensity of disturbance. Existing data could be assembled into data bases from which one could assess portions of the above hypotheses, but much research in the form of data collection and analysis remains before practical applications can be confidently described. The implications of the models for repeatable stratification of environmental variations are very wide reaching in all areas of plant community research and management.

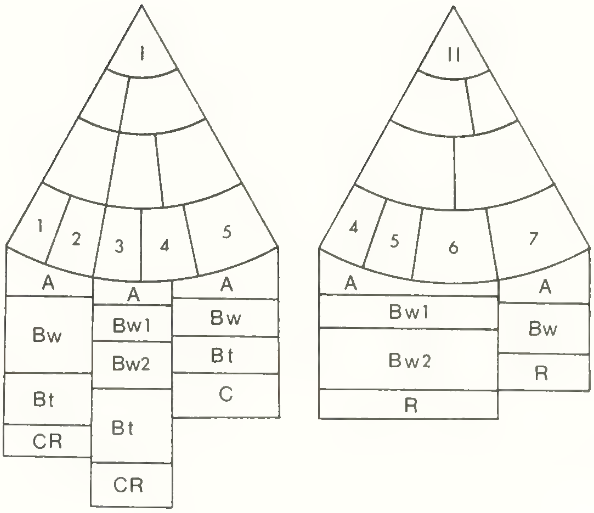

Figure 3--Conceptual model of seral plant communities in two closely associated habitat type-phases and their relationship to habitat type-phase specific soil units. Early seral communities 4 and 5 occur in both climax successions but occur over different soil units.

CONCLUSIONS

The concept that soil and vegetation both have a functional relationship to climate, parent material, relief, organisms, and time has led to the hypothesis that relationships also exist between soil and vegetation. Although they appear to respond to the same "functional factors," this cannot be extended to indicate that soil and vegetation are correlated on a one-to-one basis. The relationships between them are multifactorial and dynamic; the effect upon plant growth or reproduction of any one soil variable changes quantitatively and/or qualitatively with every variation in the complex of environmental factors. In Major's (1951) factorial approach to plant ecology, he concluded "...there are no universal correlations between vegetation and soil;...soil is not determined by vegetation, vegetation is not determined by soil; vegetation and soil develop concomitantly." Yet, it is exactly this concomitant development that provides quantifiable characteristics by which we can better understand the relationships between plant communities and soil-forming processes. Identifiable relationships can be demonstrated to exist between soils and vegetation.

The use of habitat types for refinement of silvicultural prescriptions and site productivity assessment has proven to be valuable to forest resource managers. Knowledge of the correlations between potential vegetation, soil, and site characteristics within a specific geographic region will allow more accurate classification of any given site within that region to habitat type and phase. This will also improve the identification of highly disturbed seral vegetation stages, more accurately position them within their successional development pathway, and allow for greater accuracy in predicting site capabilities and response to disturbance.

REFERENCES

Daubenmire, R. 1956. Climate as a determinant of vegetation distribution in eastern Washington and northern Idaho. Ecology Monograph. 26: 131-154.

Daubenmire, R. 1970. Steppe vegetation of Washington. Technical Bulletin 62. Washington Agricultural Experiment Station, Pullman, WA. 131 p.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Washington Agricultural Experiment Station, Pullman. 104 p.

Hann, W. J. 1982. A taxonomy for classification of seral vegetation of selected habitat types in western Montana. Ph.D. Dissertation. University of Idaho, Moscow. 235 p.

Hironaka, M.; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bulletin No. 35, Forestry, Wildlife, and Range Experiment Station, University of Idaho, Moscow. 44 p.

Huschle, G.; Hironaka, M. 1980. Classification and ordination of seral plant communities. Journal of Range Management. 33: 179-182.

Jenny, H. 1941. Factors of soil formation. New York: McGraw-Hill.

Jenny, H. 1958. Role of the plant factor in the pedogenic functions. Ecology. 39: 5-16.

Jenny, H. 1980. The soil resource. Origin and behavior. New York: Springer-Verlag. 377 p.

Johnson, C. G., Jr., Simon, S. A. 1987. Plant associations of the Wallowa-Snake Province, Wallowa-Whitman National Forest. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, R6-ECOL-TP-255A-86. 400 p.

Loucks, O. L. 1962. Ordinating forest communities by means of environmental scalars and phytosociological indices. Ecology Monograph. 32: 137-166.

Major, J. 1951. A functional, factorial approach to plant ecology. Ecology. 32: 392-412.

Neiman, K. E. 1986. Soil discriminant functions for six habitat types in northern Idaho. Ph.D. Dissertation, University of Idaho, Moscow. 174 p.

Pfister, R.; Kovalchik, B.; Arno, S.; Presby, R. 1977. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service. Intermountain Forest and Range Experiment Station. 174 p. and illus.

Sondheim, M. W.; Klinka, K. 1983. The relationship of soil and physiographic attributes to an ecological classification system. Canadian Journal Soil Science. 63: 97-112.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

Tisdale, E. W.; Bramble-Brodahl, M. 1983. Relationships of site characteristics to vegetation in canyon grasslands of west central Idaho and adjacent areas. Journal of Range Management. 36: 775-778.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil Taxonomy. Agric. Handb. 436. Soil Conservation Service, Washington. D.C. 754 p.

FLOOD-PLAIN SUCCESSION AND VEGETATION CLASSIFICATION IN INTERIOR ALASKA

Leslie A. Viereck

ABSTRACT: Twelve stages of forest succession on the Tanana River flood plain are described. Succession begins with invasion of fresh alluvium by willows and proceeds through a stage of shrubs and deciduous trees, to mature mixed-aged stands of white spruce, and finally, with the development of permafrost, to unproductive black spruce stands and bogs. A classification of the successional communities is given. Because of the formation of permafrost and resultant deterioration of the the site, a classification based on successional communities may be more useful than one based on habitat types.

INTRODUCTION

The flood plain of the Tanana River in interior Alaska provides an excellent opportunity to examine successional processes in the taiga environment. Because of the active erosion and sand and silt bar formation of this glacial river, new surfaces are continually formed and available for invasion by plants, and all stages of succession from initial vegetation on recently deposited sediment to mature forest are readily available for study. In addition, the topography is relatively flat and the river sediment deposits relatively uniform so that the main state factor regulating change is time.

The successional sequence on the flood plain also provides an opportunity to address problems of classification of both seral and mature plant communities, and especially how white spruce communities are affected by the formation of permafrost in later stages of forest succession. In this paper, the Alaska vegetation classification system (Viereck and Dyrness 1980), which is based on current rather than potential vegetation, is used to classify the flood-plain vegetation. The system uses cover of the dominant vegetation layer and the dominant species in each of the important vegetation layers.

Although succession on the flood plain proceeds as a continuum of vegetation development with time, we are able to recognize several relatively distinct stages in succession, each one on an older and slightly higher terrace of the river. Usually, the same age or stage of succession is found repeated frequently in an area, probably from simultaneous origins after episodal events such as severe flooding and sediment deposition and unusual seed years of some species. We also have found what could be considered distinct "turning points" in the successional sequence and have recently designed some of our research around these points (Van Cleve and Chapin 1986). In order of occurrence, these turning points in the flood plain succession are: (1) the stabilization of alluvium by early plant cover, (2) the formation of a complete vegetation canopy with a surface organic layer covering the mineral soil, (3) the shift from willow to alder dominance in the shrub canopy, (4) the shift in dominance from shrubs to deciduous trees, (5) the shift in dominance from deciduous to coniferous trees with the resultant establishment of feathermosses in the forest floor, and (6) the development of permafrost in the soil.

Previous papers (Van Cleve and others 1980; Van Cleve and Viereck 1981; Walker and others 1986) reported on ecosystem processes, nutrient cycling, and productivity in the successional sequence on the Tanana River flood plain. This paper will stress the classification and description of the vegetation of 12 stages of succession that occur commonly on the floodplain (fig. 1). These are modified from a previous paper in which eight stages were described (Van Cleve and Viereck 1981).

METHODS

I have been examining vegetation plots on the Tanana River for the past 25 years. Reconnaissance plots were established in 1964 and 1965 using a one plot-6 class cover estimate. In 1965 and 1966, permanent plots were established in 15 successional stands. Cover of low shrubs, herbs, mosses, and lichens was measured in 10 1-m^2 plots; shrub cover and density were measured in 10 4-m^2 plots; and each tree was measured and tagged in 500 or 1000 m^2 plots. These plots have been remeasured at about 5-year intervals. Additional information has been obtained from many other stands on the flood plain using a 20-point system of permanent plots described by Foote (1983). In addition to

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Leslie A. Viereck is Principal Plant Ecologist, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Fairbanks, AK.

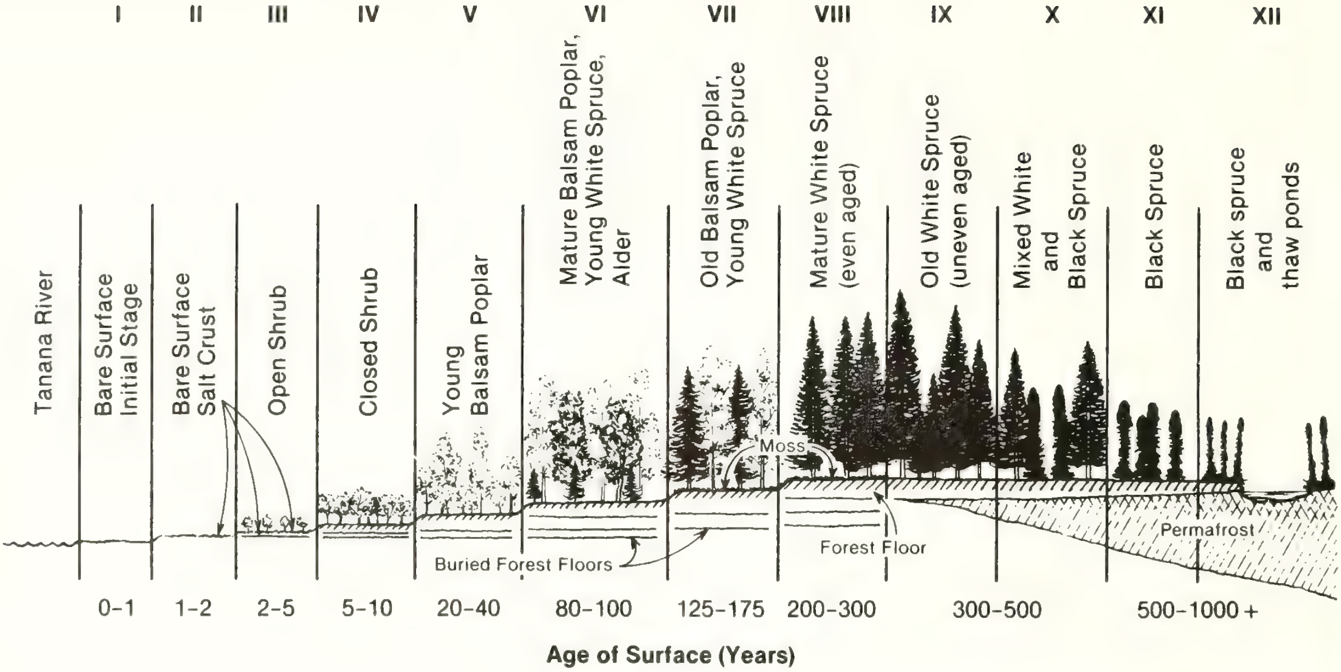

Figure 1--Cross section of 12 stages of vegetational succession on the floodplain of the Tanana River.

vegetation cover and tree and shrub density, above-ground tree biomass and annual productivity measurements have been obtained for some of the stands.

The units reported here correspond approximately to the community type used by most authors, but a rigorous vegetation analysis has not been used to determine the units. They have been subjectively selected as a result of my experience on the Tanana flood plain and examination of individual stand data from a number of measured stands.

RESULTS

Stage I. Bare Alluvium (no classification)

The recently deposited sediment bars are flooded during large portions of the summer. A few Salix and herbaceous species may become established during periods of low water, especially in late summer, but these pioneers are usually swept away or covered by silt during high water the next summer.

Stage II. Bare Recent Alluvium with Scattered Willow and Herbs (vegetation on these new surfaces is too sparse and transient to warrant classification)

Sediment surfaces that have accumulated to a height sufficient to be free of flooding for one or more years (about 2 m above the lowest winter river levels) tend to develop an evaporative crust of calcium sulfate (gypsum) and calcium carbonate on the surface. Although this salt crust may somewhat inhibit germination and establishment of some species, this is the stage at which plant colonization begins. Species colonizing these sites include Salix interior, S. alaxensis, S. nova-anglaea, Populus balsamifera, and the herbs, Equisetum palustre, E. arvense, E. variegatum, Juncus alpinus, Hedysarum mackenzii, Triglochin palustris, and Carex concinna. Some of these young stands may persist but most are destroyed by flooding and alluvial deposition. Once the Salix species are well established, they can withstand both flooding and silting and often contribute to the siltation process by slowing down the flow of the sediment-laden water.

Stage III. Open Young Willow Shrub (open Salix spp./Equisetum spp. community)

An open shrub stage, 0.5 to 1.5 m in height, occurs for 2 to 5 years after the establishment of willows. The most important species are Salix interior, S. alaxensis, S. brachycarpa, S. nova-anglaea, and S. lasiandra. Although the stand is frequently flooded, an herbaceous layer develops beneath the willows; it consists primarily of Equisetum variegatum, E. palustre, and E. hiemale. Other herbs include Carex concinna, Triglochin palustre, Castilleja caudata, Solidago canadensis, Antennaria pulcherrima, Juncus alpinus, and Spiranthes romanzoffiana. At this stage seedlings of Populus balsamifera, Alnus tenuifolia, and Picea glauca often become established, but P. glauca may not persist into later stages because of the heavy silting that occurs.

Cover of the shrub layer varies from 15 to 50 percent, and the herbaceous layer varies from under 10 percent after flooding to nearly 100 percent during summers when the stand is not flooded. At this stage, no significant development of the litter layer occurs because of the low biomass of the leaf litter and its frequent burial by silt. This stage of succession is found on terraces usually 2 to 2.25 m above the winter level of the river.

Stage IV. Closed Alder and Willow Shrubs (closed Alnus tenuifolia-Salix spp./Equisetum spp. community)

As the shrub canopy begins to close, at a height of 2 to 3 m, Alnus tenuifolia becomes co-dominant with the Salix spp. in the canopy. During the development of this stage, a major thinning of the willow stems usually takes place caused by a combination of browsing by snowshoe hares and overtopping of the willows by alders. Some species, such as Salix interior and S. brachycarpa, are completely eliminated, but others, especially S. alaxensis and S. novae-anglaea are able to persist in the dense Alnus canopy, which may reach to heights of 10 m toward the end of this stage. With the closure of the shrub canopy, the herbaceous layer becomes more depauperate, but it generally has small amounts of Equisetum arvense, E. pratense, E. palustre, Moerhingia laterifolia, and Calamagrostis canadensis. White spruce seedlings may become established in this stage.

Cover of the shrub layer is usually 80 to 100 percent, but herbaceous layer cover is usually under 25 percent. At this stage, a heavy leaf and woody litter develops on the forest floor, with litter fall of as much as 250 $g/m^2/yr$. The litter layer is occasionally buried by sediment deposition during flooding, however. Productivity of these stands is high, on the order of 4000-4750 kg/ha/yr (Van Cleve and others 1971) and amounts of N in the system increase markedly during this period through N-fixation by alder root nodules. These closed shrub stands are usually on terraces that are 0.5 m above the stage III, or 2.5 to 2.75 m above the winter low-water level, indicating that sediment deposition from flooding is still a factor during their development. These closed shrub stands dominate for 10 to 20 years and occupy relatively large areas on the flood plain.

Stage V. Open Balsam Poplar With Dense Alder Understory (open Populus balsamifera/Alnus tenuifolia/Equisetum spp. community)

At about 20 to 30 years after establishment of vegetation on alluvial deposits, Populus balsamifera stems reach through the shrub canopy and begin to dominate the sites. The tree canopy remains open, and the cover of Alnus tenuifolia begins to decline from the stage IV levels. The less shade-tolerant willows usually drop out of the stands or persist only as scattered individuals. More shade-tolerant shrubs, such as Rosa acicularis and Viburnum edule, become established in the understory. The herb layer remains relatively scattered and is dominated by Equisetum arvense and E. pratense. Some herbaceous species that will persist into the later conifer stages begin to appear during this stage--Pyrola asarifolia, P. segunda, and Geocaulon lividum.

Stage VI. Closed Balsam Poplar with Alder Shrub Understory (closed Populus balsamifera/Alnus tenuifolia/Rosa acicularis/Equisetum spp. community)

In mature balsam poplar stands where the canopy has closed by crown expansion, cover of the understory alder shrub layer is reduced. In addition, both Rosa acicularis and Viburnum edule become more important in a low shrub stratum. The herbaceous layer is similar to that found in stage V except that total cover is somewhat greater. The shrub layer cover is about 50 percent and herbaceous cover ranges from 25-50 percent. Tree basal area reaches 35 to 40 m^2/ha, and above-ground tree productivity reaches a maximum for the successional sequence on these sites--as high as 9500 kg/ha/yr in 50- to 75-year-old stands (Viereck and others 1983). A heavy litter layer also develops in these stands. Examination of the soil profile reveals many buried organic layers, indicating that sediment deposition from flooding is still common. The terraces on which these stands are found are 3 to 3.5 m above the winter river levels, and flooding occurs about once per decade. This deciduous tree stage may persist for 100 years before it is replaced by white spruce forests.

Stage VII. Mixed Balsam Poplar and White Spruce (closed Populus balsamifera-Picea glauca/Alnus tenuifolia/Equisetum spp. community)

This mixed balsam poplar and white spruce stage is transitional between the deciduous forest and the conifer forest stages. It marks an important turning point in the successional sequence on the flood plain. White spruce may become established as early as stage IV and develop concurrently with the balsam poplar, but more commonly white spruce seedlings first come in under the young balsam poplar canopy. In the mixed poplar-spruce stands, the canopy of balsam poplar is once again open; heavy mortality in the poplars is usual, especially as they reach 100 years of age. White spruce remains under the balsam poplar canopy, but it may have as much as 50 percent of the tree canopy cover. In this stage, the Alnus tenuifolia shrub cover is usually as low as 25 percent, and Rosa acicularis and Viburnum edule are common.

Deciduous leaf and twig litter form a thick layer on the forest floor. On downed logs and under some of the larger spruce, however, patches of feathermosses become abundant in later successional stages. Once white spruce reaches dominance in these stands, numbers and cover of balsam poplar rapidly decrease, primarily as a result of stem rot and wind breakage.

Consequently, transitional stands of this nature are not widespread on the flood plain.

Stage VIII. Mature Even-aged White Spruce Stands (closed Picea glauca/Rosa acicularis/Linnaea borealis/Hylocomium splendens community)

Most of the 100-year-old white spruce stands on the Tanana flood plain have a closed canopy of more than 75-percent cover. A few old, usually decadent balsam poplar are scattered throughout the stand. As a consequence of the dense tree canopy, the alder shrub layer is usually reduced to an occasional clump. Most stands, however, have a well-developed shrub layer of Rosa acicularis and an occasional Viburnum edule. The low shrub and herb layers together comprise about 25-percent cover and are composed primarily of Linnaea borealis, Equisetum arvense, E. pratense, Geocaulon lividum, Pyrola secunda, and P. asarifolia. Hylocomium splendens provides most of the moss cover, which approaches 100 percent, but Rhytidiadelphus triquetrus can be an important part of the moss layer in some stands.

White spruce stands on the Tanana flood plain are usually at least 3.75 to 4 m above the winter low-water level, and flooding is infrequent. Tree density may be as high as 2000 tree/ha in the younger stands but tends to be reduced to 500 to 750 trees/ha in older stands. Average diameters of the spruce are about 30 cm, and basal area ranges from 30-60 m^2/ha. Annual tree productivity is high, reaching to 5400 kg/ha per year (Van Cleve and others 1980). These stands are the prime commercial forest stands on the floodplain.

Stage IX. Old, Uneven-Aged White Spruce Stands (open Picea glauca/Alnus crispa-A. tenuifolia/Vaccinium vitis-idaea/Hylocomium splendens community)

On older terraces, generally located well back from the river, the white spruce stands are more open and uneven aged. Juday and Zasada (1984) have shown the change in structure and age of white spruce on different-aged terraces on Willow Island on the Tanana flood plain. Paper birch (Betula papyrifera) may occur in highly variable numbers in these stands. The average white spruce cover is as low as 30 to 50 percent, and tree ages range from 130 to 350 years. Both Alnus crispa and A. tenuifolia are the dominant tall shrubs, with cover ranging from 10 to 80 percent, depending in some measure on the density of the tree canopy. Other commonly occurring shrubs are Rosa acicularis and Viburnum edule. The dominant species in the low shrub-herb layer is Vaccinium vitis-idaea with lesser amounts of Linnaea borealis, Equisetum arvense, Cornus canadensis, and Geocaulon lividum. Moss cover is dense, primarily Hylocomium splendens, but other mosses such as Pleurozium schreberi and Rhytidiadelphus triquetrus are also common.

These stands are located on high river terraces that are only infrequently flooded. A layer of intermittent permafrost is usual in most of the stands, marking an important turning point in the successional sequence. Tree growth is slower--and thus forest productivity lower--than in the younger, first-generation spruce stands on the flood plain.

Stage X. Mixed White and Black Spruce (open Picea glauca-P. mariana/Ledum groenlandicum-Vaccinium vitis-idaea/Hylocomium-Pleurozium community)

Mixed stands of white spruce and black spruce occur occasionally on the Tanana River flood plain and are transitional between the stands on the young active flood plain and those of the older terraces. The stands are open with canopy cover as low as 25 to 50 percent. Paper birch also generally occurs in small numbers in the tree layer. The spruce have diameters averaging 20 cm and are uneven aged, with ages ranging from 150 to 250 years. The tall shrub layer is sparse and is made up of Alnus crispa, Rosa acicularis, and Salix glauca. Low shrubs are abundant with a cover of more than 50 percent, with Ledum groenlandicum and Vaccinium vitis-idaea being the most abundant. Empetrum nigrum, Linnaea borealis, and Vaccinium uliginosum also occur in smaller amounts. Common herbs include Equisetum arvense, Geocaulon lividum, Cornus canadensis, Calamagrostis canadensis, and Arctagrostis latifloia. Moss cover of Hylocomium splendens and Pleurozium schreberi is well developed, with a total cover of about 75 percent. Lichen cover averages 15 to 35 percent and is comprised primarily of Peltigera aphthosa, P. canina, Cetraria islandica, and several species of Cladonia.

These stands are always underlain by permafrost, and the active layer may be shallow, with thicknesses of 50 to 60 cm being most common. Tree growth is slow, and forest productivity is low.

Stage XI. Open Black Spruce (open Picea mariana/Ledum groenlandicum/Hylocomium splendens community)

Stands of black spruce are common on the oldest terraces of the active flood plain. Black spruce is the dominant tree, but scattered white spruce, tamarack (Larix laricina), and paper birch may also be present. Although tree density is high (2400 stems/ha), the canopy is usually open, with cover of 40 to 60 percent. Tall shrubs, primarily Alnus crispa and Rosa acicularis, are scattered in the stand, with cover of about 10 percent. A low shrub stratum of Vaccinium vitis-idaea, Ledum groenlandicum, and Empetrum nigrum forms a nearly continuous cover. Herb cover is low; Equisetum scirpoides, Geocaulon lividum, and Calamagrostis canadensis are the most common. A thick mat of Hylocomium splendens is nearly continuous. Sphagnum spp. often occur in wet depressions in the stand.

These stands are closely underlain by permafrost, and the active layer is usually less than 60 cm thick. Forest productivity is low. For one stand, we found that the annual above-ground forest productivity was only 75 g/m^2 (Viereck and others 1983).

Stage XII. Black Spruce, Thaw Ponds, and Bogs (classification of the mosaic of vegetation types on the oldest terraces is beyond the scope of this paper)

The final stage of succession on the Tanana flood plain is represented by terraces that are a mosaic of open or woodland black spruce stands similar to those of stage XI interspersed with depressions or small ponds. These low, poorly drained areas originate in the melting of the underlying permafrost, which is rich in ice lenses or wedges (Benninghoff 1952; Drury 1956). Depressions are often water-filled or may be in the process of filling and bog formation. A wide variety of vegetation types occurs in these areas, depending on the stage of development of the thaw pond or bog. Sphagnum mosses and several species of Carex and Eriophorum are the major species. Three community types--a sedge meadow, an Eriophorum vaginatum tussock, and a Sphagnum bog type--have been described on older river terraces in the general area of the Tanana River (Calmes 1976).

CONCLUSIONS

As discussed by Steele (1984), when successional communities are classified, grouping successional communities occurring within one ecosystem (habitat) type is best. Whereas the site-type classification is based on climax ecosystems with time as a relative constant, successional classification should hold the environment relatively constant and examine communities over a time sequence (Arno and others 1986). The successional time should be characterized by the communities rather than by years since the beginning of the successional sequence.

In the sequence I have described for the Tanana River flood plain, the main variable is time: time since the formation of the alluvial deposit and the establishment of the first vegetation on the new surface. This sequence then should fit the criteria for a successional sequence within a single habitat type. Certain environmental characteristics also change with time, however, either directly or indirectly as a result of the developing vegetation. The three most important environmental changes on the Tanana River flood plain are the height above the river and, thus, the frequency of flooding; access to the underlying water table for water and nutrients; and the development of permafrost in the later stages of succession as a result of the thick moss layer on the forest floor.

The permafrost layer causes profound changes in the site, tending to convert productive white spruce sites to low-productivity black spruce sites. The classification of the soil actually changes with the development of permafrost. Young soils on the active flood plain are in the Salchaket series (Typic Crofluvents). When permafrost enters the soil, however, they are classified in the Tanana, Bradway, or Goldstream series as Pergelic Cryaquepts, a change in soil orders from Entisols to Inceptisols (Furbush and Schoephorster 1977). With the impervious permafrost layer, the soils become waterlogged even though they were previously well drained. Soil temperatures in the stands are low, decomposition slows, and nutrients become limiting to tree growth (Van Cleve and others 1980). Productivity of these sites is low and concentrated in the moss layer.

How should this situation be handled under the ecosystem type classification? What is the "climax" type for these sites? Is it the productive mature white spruce stand, the unproductive black spruce stands, or the black spruce-bog mosaic found on the older terraces? From the point of view of managers, a classification based on the successional vegetation might be more useful than one based on habitat type. Logically young productive white spruce stands on the flood plain would need a different management strategy than older less productive stands underlain by permafrost (Zasada 1984). This logic has been shown on Willow Island on the Tanana River flood plain, where three different ages of white spruce stand were experimentally logged in 1983. The reaction of vegetation and soils to logging was very different in three different ages of white spruce stands (Dyrness and others, in press). In a previous paper (Viereck and others 1986), we separated the flood-plain vegetation into two main site types: the white spruce type on the active flood plain and the black spruce-permafrost type on the older terraces. This might be useful for developing a more detailed classification even though it does not rigidly fit into the site type classification based on "climax" vegetation.

SUMMARY

On the Tanana River flood plain, distinct successional communities can be recognized and classified. They begin with open willow stands on recently deposited alluvium and proceed through shrub and deciduous tree stages to productive white spruce stands. With time, permafrost develops in these mature white spruce stands, and they are replaced by low-productivity black spruce stands and eventually, on older terraces, by a mosaic of black spruce and bog communities. Classifying these sites by habitat type is difficult unless the system is modified to recognize the deterioration of the site when permafrost develops. A classification that recognizes the successional communities leading to mature white spruce stands, the various ages of the white spruce stands, and the deterioration of the site with the developing permafrost might be the most useful to forest managers.

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REFERENCES

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1986. Characterizing succession within a forest habitat type--an approach designed for resource managers. Res. Note INT-357. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Benninghoff, W. S. 1952. Interaction of soil frost phenomena. Arctic. 5(1): 34-44.

Calmes, Mary A. 1976. Vegetation pattern of bottomland bogs in the Fairbanks area, Alaska. Fairbanks, AK: University of Alaska. 104 p. M.S. Thesis.

Drury, W. H., Jr. 1956. Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska. Contribution Gray Herbarium, 178. 130 p.

Dyrness, C. T.; Viereck, L. A.; Foote, M. J.; Zasada, J. C. [In press]. The effect on vegetation and soil temperature of logging flood-plain white spruce. Res. Pap. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Foote, M. Joan. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of interior Alaska. Res. Pap. PNW-307. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 108 p.

Furbush, Clarence E.; Schoephorster, Dale B. 1977. Soil survey of Goldstream-Nenana area, Alaska. Fairbanks, AK: U.S. Department of Agriculture, Soil Conservation Service. 44 p.

Juday, Glenn P.; Zasada, John C. 1984. Structure and development of an old-growth white spruce forest on an interior Alaska floodplain. In: Meehan, William R.; Merrell, Theodore R., Jr.; Hanley, Thomas A., eds. Fish and wildlife relationships in old-growth forests: Proceedings of a symposium; 1982 April 12-15; Juneau, AK. Morehead City, NC: American Institute of Fishery Research Biologists: 227-234.

Steele, Robert. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58(1): 29-39

Van Cleve, Keith; Viereck, Leslie A.; Schlentner, Robert L. 1971. Accumulation of nitrogen in alder (Alnus) ecosystems near Fairbanks, Alaska. Arctic and Alpine Research. 3(2): 101-114.

Van Cleve, K.; Dyrness, C. T.; Viereck, L. A. 1980. Nutrient cycling in interior Alaska floodplains and its relationship to regeneration and subsequent forest development. In: Murray, M.; Van Veldhuizen, R. M., eds. Forest regeneration at high latitudes. Gen. Tech. Rep. PNW-107. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 11-18.

Van Cleve, Keith; Viereck, Leslie A. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. In: West, Darrell C.; Shugart, Herman H.; Botkin, Daniel B., eds. Forest succession concepts and application. New York: Springer Verlag: 185-211.

Van Cleve, K.; Chapin, F. S., III. 1986. Successional processes in taiga forests of interior Alaska: a Long Term Ecological Research Program (LTER) for study of controls of subarctic forest development. Proposal submitted to the Long Term Research Program. Washington, DC: National Science Foundation. 128 p.

Viereck, Leslie A. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. Arctic and Alpine Research. 2(1): 1-26.

Viereck, Leslie A.; Dyrness, C. T.; Van Cleve, Keith; Foote, M. Joan. 1983. Vegetation, soils, and forest productivity in selected forest types in interior Alaska. Canadian Journal of Forest Research. 13(5): 703-720.

Viereck, Leslie A.; Dyrness, C. T. 1980. A preliminary classification system for vegetation of Alaska. Gen. Tech. Rep. PNW-106. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 38 p.

Viereck, L. A.; Van Cleve, K.; Dyrness, C. T. 1986. Forest ecosystem distribution in the taiga environment. In: Van Cleve, K; Chapin, F. S., III; Flanagan, P. W.; Viereck, L. A.; Dyrness, C. T., eds. Forest ecosystems in the Alaska taiga. A synthesis of structure and function. New York: Springer Verlag: 22-43.

Walker, Lawrence R.; Zasada, John C.; Chapin, F. Stuart, III. 1986. The role of life history processes in primary succession on an Alaska floodplain. Ecology. 67(5): 1243-1253.

Zasada, John C. 1984. Site classification and regeneration practices of floodplain sites in interior Alaska. In: Murray, M., ed. Forest classification at high latitudes as an aid to regeneration. Gen. Tech. Rep. PNW-177. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 35-39.

Zasada, J. C.; Slaughter, C. W.; Argyle, J. D.; Teutsch, C. E. 1987. Winter logging on the Tanana River floodplain in interior Alaska. Northern Journal of Applied Forestry. 4(1): 11-16.

OPERATIONAL USE AND EVOLUTION OF A PLANT ASSOCIATION CLASSIFICATION

Miles A. Hemstrom and Michael Frazier

ABSTRACT: Competitive interactions between Douglas-fir and salmonberry are a major silvicultural concern in the Oregon Coast Range. A plant association classification provided an initial focus on sites where intense competition is likely. Subsequent examination at a level below the plant association revealed topographic variants of salmonberry-dominated plant associations where competition is most severe. Topographic classes will be useful in predicting development of intense competition and will be incorporated in future revisions of the plant association classification.

INTRODUCTION

Plant association classifications, particularly when actively used for natural resource management, cannot be static entities. Application frequently leads to views of the vegetation/environment complex in ways and at levels of detail not possible to incorporate in the initial classification effort. The classification is constantly being refined to make it more useful and meaningful. The types and levels of use will guide the direction and degree of evolution. An example from the Siuslaw National Forest illustrates this process.

The Siuslaw National Forest has abundant natural resources, including fish, water, wildlife, and timber. Climate and abundant resources make the Forest one of the most productive areas in the world for timber and fish. Accurate resource information is critical to program and project planning. Plant associations are being actively used as key stratification elements for both basic resource inventory and as predictive tools. In this paper, we focus on their use in the reforestation phase of intensive timber management, especially for predicting the severity of competition between shrubs and conifers in the salmonberry associations.

Physical and Vegetative Setting

The Siuslaw National Forest spans about 630,000 acres of the Oregon Coast Range between Tillamook and Reedsport. The climate is distinctly maritime with abundant winter precipitation, relatively dry summers, and mild temperatures throughout the year. Most precipitation falls as rain from October through March and yearly averages range from 80 to over 150 inches (U.S. Department of Commerce 1965). Mean minimum winter air temperatures seldom average below freezing and mean maximum summer air temperatures rarely average above 80 degrees Fahrenheit (Johnsgard 1963).

Interbedded sandstones, siltstones, and mudstones in the southern half of the Forest have been highly eroded, resulting in a steep, highly dissected topography. Relatively resistant igneous bedrock, most common in the north half of the Forest, lies under the highest peaks, which rise to nearly 3000 feet. Stony, sandy loam inceptisols are common in steep, colluvially active topography. Ultisols of deep clay have developed on more stable inland topography.

Two conifer series occur on the Forest (Hemstrom and Logan 1986). Sitka spruce and western hemlock are the climax species in the Sitka spruce series found near the Pacific Ocean where the maritime climatic influences are most pronounced. The first major ridges inland reduce maritime climatic influences, leaving western hemlock the dominant climax species in the western hemlock series. Western redcedar is potentially a sub-dominant climax species throughout the area. Douglas-fir and red alder, alone or in combination, dominate existing natural stands. Most natural stands are about 110 years old, a result of a series of wide-spread fires in the mid-nineteenth century. Climax stands are exceedingly rare.

Hemstrom and Logan (1986) described 23 plant associations on the Forest. Associations in which salmonberry is common fall into three major groups, as moisture conditions range from mesic to xeric.

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Miles A. Hemstrom is Area Ecologist, Willamette and Siuslaw National Forests, Forest Service, U.S. Department of Agriculture, Eugene, OR; Michael Frazier is Silviculturist, Mapleton Ranger District, Siuslaw National Forest, U.S. Department of Agriculture, Mapleton, OR.

Salmonberry associations--Salmonberry plant associations dominate the wettest sites, generally on lower slopes and in concave topography. The dense shrub layer persists for an indefinite period of time and dominates early seral communities. Conifer establishment can be difficult and succession to climax very slow. Red alder and scattered conifers dominate the canopy on most sites. Both crop trees and salmonberry grow rapidly during the first five years in plantations (fig. 1). Mean crop tree height exceeds mean salmonberry height by year five following harvest.

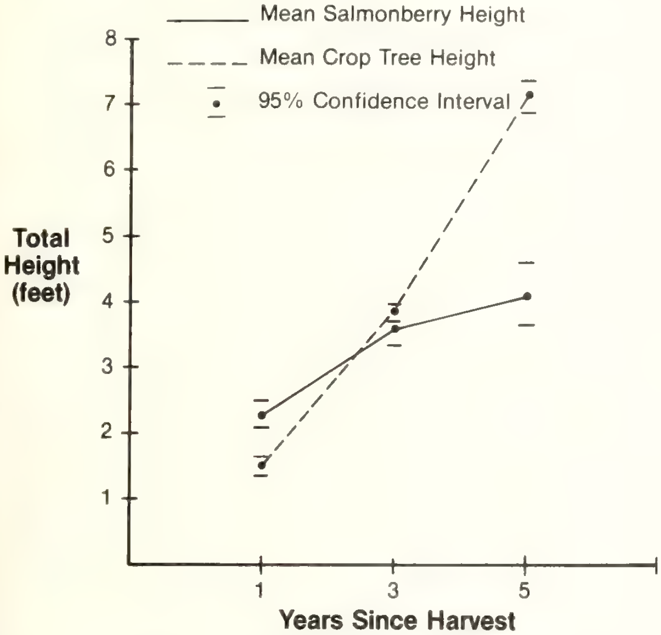

Figure 1--Mean salmonberry and crop tree height at one, three, and five years following harvest in salmonberry associations.

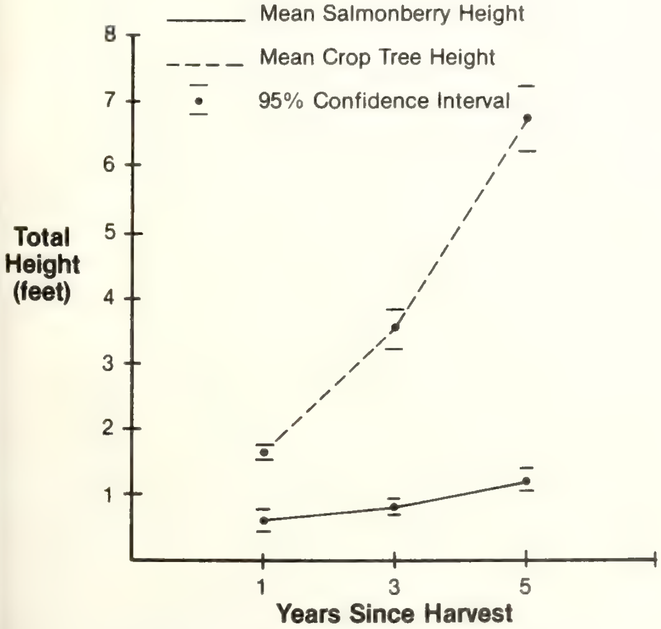

Figure 2--Mean salmonberry and crop tree height at one, three, and five years following harvest in swordfern associations.

Swordfern associations--Swordfern plant associations are common on more well-drained, middle and upper-slopes. Salmonberry may occur in early seral communities, but is not as vigorous. Well-stocked Douglas-fir stands, often containing red alder, dominate most sites. Crop trees are generally taller than salmonberry in most plantations by five years following harvest (fig. 2).

Salal assocations--Salal plant associations are found on relatively dry sites. Red alder and salmonberry are not abundant. Most stands consist of nearly pure Douglas-fir. Crop trees are substantially taller than salmonberry in plantations by five years following harvest (fig. 3).

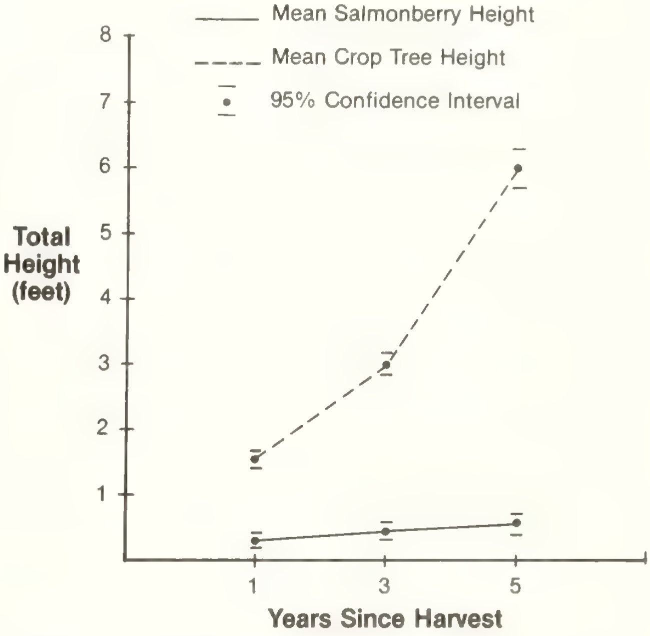

Figure 3--Mean salmonberry and crop tree height at one, three, and five years following harvest in salal associations.

Management Setting

Early competition between conifers and other vegetation is a major concern in this area of high productivity. Planted conifers have rapid juvenile height growth. They will eventually dominate and shade out competing shrubs and hardwoods, unless they are weakened by too long a period in the shade. This situation can occur either as a simple result of competition or because trees have fallen behind for other reasons, including animal damage.

The most significant periods when competition between conifers and shrubs or hardwoods may produce unacceptable seedling mortality include:

1. salmonberry and associated vegetation up to five years following harvest. Rapidly resprouting shrubs create heavy early competition and animal cover, influencing crop trees before they are established.

2. rapidly growing red alder over-topping established conifers five to ten years following harvest. This situation may develop on different areas than salmonberry competition.

In this paper, we will focus on early competition between conifers and salmonberry. Plantation establishment in salmonberry-dominated areas has sometimes seemed an intractable problem, especially given the administrative loss of chemical herbicides. Even when herbicides are available, areas where the problem exists often cannot be treated because of proximity to open water. Manual methods have sometimes required repeated treatment because of rapid sprouting. Experience with this situation has led managers to expensive preventive measures like pre-burn herbicide applications or slashing treatments. Most managers believe that plantation establishment in these zones will be very difficult without burning or herbicides or both. While this is perceived to be the case on a large portion of salmonberry-dominated areas, many areas have been successfully managed without extraordinary measures. The major problem has been predicting the locations of difficult areas.

Silviculturists on the Siuslaw National Forest have worked for some time to understand the complex competitive situation in early plantation development. Believing that stratification by plant association would aid this understanding, they incorporated plant association into the design of a reforestation survey system. This system is an organized method for collection and storage of data on surveys taken in the course of reforestation examinations typically performed at one, three, and five years following site preparation. The system is common across the Forest. Data collected for each plot include plot location (on a grid for each survey area), aspect, slope, stocking, crop tree attributes (species, height, height increment, animal damage), height and cover for major shrub and herb species. Plant association for each plot is included from a map prepared before harvest. The grid of plot locations is flagged in the field and used, as much as possible, in subsequent plantation examinations. Treatment history, in the form of codes for release treatment and date of the latest tree planting effort, are included for each plot. Intensity of prescribed burns was recorded in more recent examinations. The data set does not yet contain a substantial amount of information on burn intensity. The data are organized in a data file and updated yearly. There are over 50,000 plots in the file as of August 1987.

The information in the database is an extensive sample of vegetation development after various treatments on all the environments represented across the Forest. It offers an opportunity to examine reaction of vegetation to treatment across a wide range of environment and to develop predictive tools. The salmonberry-conifer competitive interaction was the focus of initial efforts to use the data set to develop predictive tools. The specific objective of these initial efforts was to learn whether there are variants within the salmonberry plant associations which could be identifed by site features and where competition is so severe that crop tree establishment is improbable without extra measures.

METHODS

The approach we used generally involved two steps:

1. identifying a subset of reforestation survey plot data where competition from salmonberry was apparently severe and where crop tree performance was unacceptable,

2. examining the plots within the subset in some detail to discover whether they had common attributes that would help predict the severe competition conditions.

Identification of the Severe Competition Subset

The first step in the process of identifying a subset where salmonberry competition was apparently severe involved focusing on five-year reforestation survey data. Plantations at age five have gone through the initial establishment period. The rate and direction of vegetation succession has become obvious and initial crop tree success is apparent. This five-year set of data from Mapleton District contained about 9400 plots.

The next step in screening the data involved eliminating plots from areas that had been replanted or inter-planted with conifers after the failure of an initial planting. This eliminated plots (about 24 percent of the five-year data set) where the conifers might be substantially younger than the shrubs.

A similar screen involved eliminating plots from areas previously treated with manual, chemical, or other means to reduce shrub competition. This eliminated plots (about 14 percent of the five-year data set) where shrub height reflected treatments. This selection may also eliminate some sites where salmonberry grows most rapidly and which, therefore, might have been treated to reduce shrub competition. To ensure that these sites were sampled, we included some three-year reforestation survey plots from areas subsequently released.

We isolated a group of plots from salmonberry plant associations where apparent competition between conifers and shrubs was severe enough that either seedling mortality was high or most seedlings were over-topped by shrubs at age five. We assumed that salmonberry less than 4 feet tall and <50 percent cover at year 5 does not pose survival problems for conifers, since mean conifer height at age five exceeds 4 feet (fig 1). We grouped plots into subsets where salmonberry cover was incrementally increased from at least 50 percent to at least 70 percent and salmonberry height was incrementally increased from greater than 4 feet to greater than 7 feet. The resulting sets of plots were a series in which salmonberry cover and height increased from at least 50 percent and 4 feet to at least 70 percent and 7 feet. For each of these sets, we created frequency tables showing crop tree presence and height, salmonberry cover and height, and the difference in height between crop trees and salmonberry.

We examined the trends of crop tree presence and height and difference in height between crop trees and salmonberry among the sets of plots as salmonberry became more vigorous. Percent of plots without conifers is significantly higher ($p < 0.01$) with each salmonberry height increment of 1 foot above 4 feet. Salmonberry of at least 50 percent cover and at least 6 feet tall at year five is associated with significant ($p < 0.01$) inceases in conifer mortality and, less clearly, with changes in conifer height growth. Increases in salmonberry cover above 50 percent were not associated with significant changes in mean crop tree height or the percent of plots without crop trees.

We chose the subset where salmonberry cover is greater than or equal to 50 percent and height is greater than or equal to 6 feet to pursue site attributes associated with vigorous salmonberry and unacceptably low conifer survival. The majority (64 percent) of plots in this set lack conifers. Salmonberry is taller than crop trees in over half (54 percent) of the plots which contain trees (fig. 4).

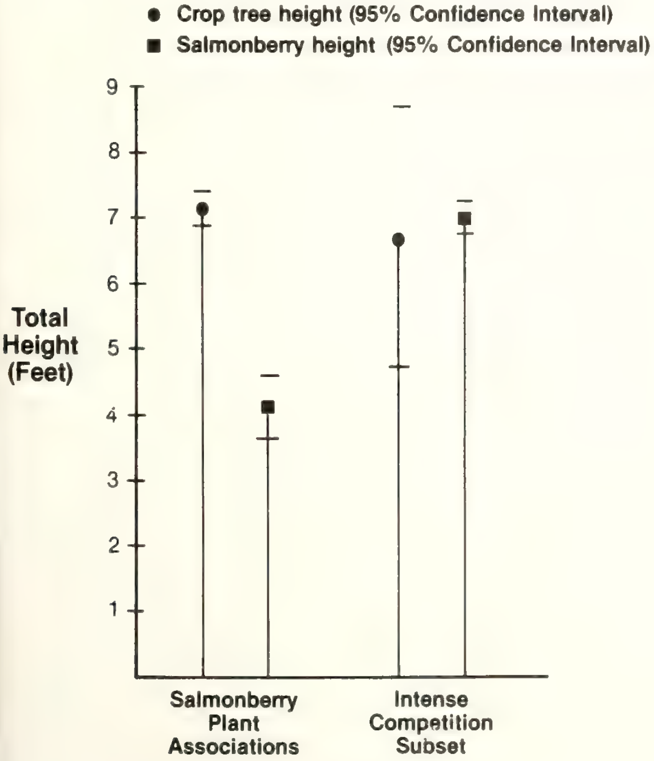

Figure 4--Mean salmonberry and crop tree height at year five following harvest in the salmonberry plant associations as a whole and in the intense salmonberry competition data set.

We recognize that salmonberry vigor and conifer height and survival lie along a continuum. Definition of "severe" salmonberry competition is somewhat arbitrary. From a management perspective, conifer survival to year five in the subset we chose is unacceptable. This set of plots contains 9 percent of all five-year plots where salmonberry had not been released and could be said to represent the worst 9 percent of the salmonberry association group spectrum.

Detailed Examination for Common Attributes

The conditions which allow salmonberry to reach at least 6 feet in height and at least 50 percent cover could be environmental, the result of management activities, or both. Slash burning, for example, has long been believed to slow salmonberry recovery. Cool, spotty burns could allow rapid salmonberry recovery. Poor burns might well be associated with particular environmental conditions, such as slope, aspect, and topographic position.

All of the reforestation surveys in the vigorous salmonberry data set were relocated in the field and on aerial photographs. A set of location and topographic attributes was identified for each plot, including: geomorphic zone (Berry and Maxwell 1981), distance from the ocean, aspect of the major slope on which the plot is located, plot position on the major slope (ridge, upper slope, middle slope, lower slope, bottom), plot elevation, and local topographic features. Local topographic features pertained to the immediately adjacent slope which feeds ground water directly into the plot area. Local topographic information included: distance to the drainage bottom, distance to the top of the slope, slope steepness, slope aspect, and whether the topography was concave, flat or convex in the horizontal and vertical planes. A total of 187 plots were relocated and examined.

RESULTS

Local topographic factors were the most consistent descriptors of the vigorous salmonberry plot set. Most of the plots (95 percent of the relocated plots) fell into one or more of four classes (fig. 5). Over half of the plots (53 percent) were in the riparian fringe. We defined the riparian fringe to be within 100 feet of the stream bottom or less than 25 percent of the distance up the drainage slope from the bottom.

Among plots not found in the riparian fringe, a substantial portion (32 percent) were on steep slopes facing west, northwest, north, northeast, and east. Steep slopes were defined to be over 50 percent slope. While all aspects were about evenly represented in the total five-year data set (fig. 6), very few of the relocated plots were on west aspects (fig. 7). If we eliminate west aspects, this topographic situation describes 30 percent of the relocated plots.

Eight percent of the relocated plots were in topographic depressions outside steep, northerly aspects and the riparian fringe. On these sites,

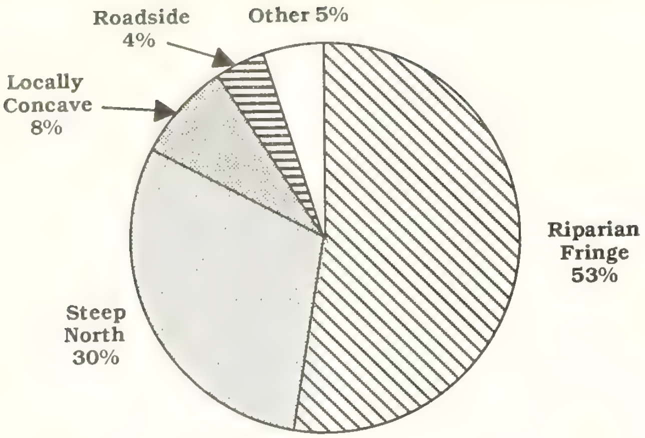

Figure 5--Percent of relocated reforestation survey plots in salmonberry associations falling into four topographic categories.

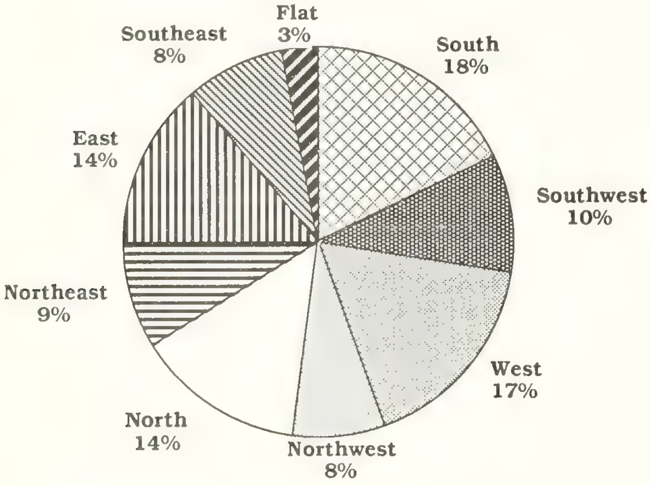

Figure 6--Distribution of aspect in all five-year reforestation survey plots.

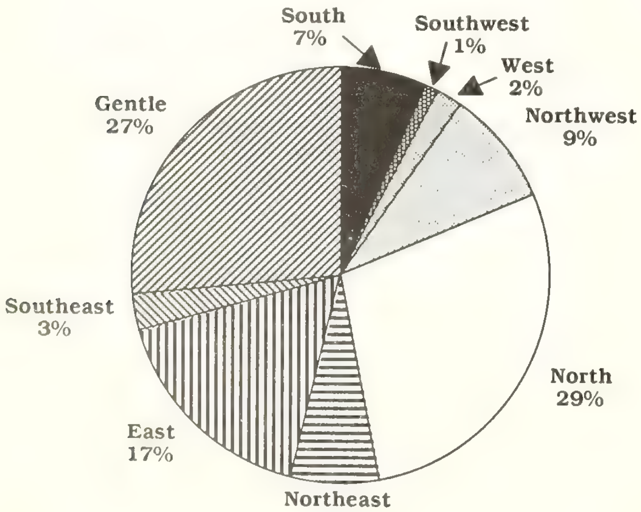

Figure 7--Distribution of aspect in relocated reforestation survey plots from the intense salmonberry competition data set.

micro-relief was concave in either the horizontal or vertical planes or both.

Another group of plots (4 percent of the 187 plots) were immediately adjacent to and downhill from a road or landing.

The remaining plots (5 percent of the relocated plots) did not form a discernable pattern, given the field attributes we measured. We suspect that these may be on sites with high ground water tables from seeps, on sites in shade during winter as a result of their large-scale topographic location, or on sites shaded by an adjacent stand edge resulting from timber harvest.

DISCUSSION

Our approach is descriptive, rather than experimental. For this reason, we cannot reach firm conclusions about why salmonberry is so vigorous in the areas we have described. Nor can we say with certainty that competition from salmonberry is the cause of poor conifer performance. However, we can develop hypotheses about the factors contributing to the coincidence of vigorous salmonberry growth and poor conifer performance in each of the four topographic conditions.

Lower slopes in the riparian fringe receive abundant sub-surface moisture from upslope. Salmonberry requires abundant soil moisture for optimum development. Douglas-fir, the major conifer species, does well with abundant, but not excessive, soil moisture. Soil moisture on lower slopes may occasionally be excessive for optimal Douglas-fir growth (Perry 1984). The competitive balance may shift in favor of salmonberry as a consequence of optimal height growth in salmonberry and possibly reduced Douglas-fir height growth. Topographic shading in narrow drainage bottoms may reduce photosynthetic output of Douglas-fir during winter when salmonberry has lost its leaves. Lower slopes on the riparian fringe often do not burn well or are protected from fire during slash burns, allowing salmonberry to get a rapid start following poor site preparation.

Steep, northerly facing slopes are topographically shaded during the winter when salmonberry is leafless. Direct solar radiation goes to zero by early November on north-facing slopes over 50 percent at 45 degrees north latitude. Net photosynthesis is relatively high throughout the winter at lower elevations in western Oregon (Waring and Franklin 1979). Winter photosynthesis during the period when salmonberry lacks leaves may be critical for conifer growth in severe competition situations. Conifers on sites which receive no direct solar radiation during winter can use only relatively low levels of indirect radiation for photosynthesis. In fact, conifers were shorter in this topographically shaded subset than in the riparian fringe subset ($p < 0.1$), but salmonberry height was not significantly different (fig. 4).

Soil moisture conditions in concave topography may be similar to those in the riparian fringe. The sample data set is too small to draw any inferences about relative conifer and salmonberry heights. While moist, concave topography may be a relatively minor part of the severe salmonberry competition situation on Mapleton District, it might be important in other areas of the Oregon Coast Range.

Moisture conditions likely also play a part in areas adjacent to and downhill from roads and landings. Soils of both roads and landings are compacted. Precipitation runs off, increasing water availability in adjacent soils.

While we cannot make conclusions about cause and effect, our approach is useful. We have formulated working hypotheses about the conditions associated with intense salmonberry competiton on the Mapleton District. These hypotheses should be tested by sampling sites not included in our data to see if those that fit one of our four topographic classes in salmonberry associations are indeed sites with intense salmonberry competition.

Another follow-up investigation should involve experimental manipulations or more closely controlled comparisons to test specific parts of the hypothesis. For example, the importance of topographic shading could be examined by comparing two areas with identical plant association and site factors, with one shaded in winter by adjacent uncut timber and the other open to winter sun.

Salmonberry plant associations as a whole indicate sites with a narrow window of reforestation opportunity. Outside the most vigorous salmonberry sites, delays in stand establishment from poor planting stock and unpredicted animal damage can make stand establishment difficult. If the original planting fails, a second attempt may require expensive treatments. Within salmonberry associations, riparian fringes, topographically shaded areas, topographic depressions, and areas just downhill from compacted roads and landings are likely to be difficult and expensive to reforest even with good stock and animal damage control.

It appears in retrospect that we may have generalized our reforestation treatments in salmonberry associations in response to some general observations about vegetation development. We now use operational data to focus our concept of the problem, which will allow more site-specific application of treatments. This process will continue to be used in analagous cases. The combination of operational data analysis and the ability to analyze geographic information at a landscape scale will be a very powerful planning tool in the future.

This approach has also proven useful in refining the plant association classification. This investigation made clear the fact that the salmonberry associations are not homogeneous with respect to tree and shrub growth. Topographic position has an important impact on early seral competitive interactions. The impact is not transient. Early establishment of long-lived conifers shapes community composition and structure for hundreds of years. Future revisions of the plant association classification will include topographic variants of the salmonberry associations. They will follow the form western hemlock/salmonberry (riparian), for example. Other groups of plant associations may contain similar variation which will come to light in the on-going process of application.

REFERENCES

Berry, J.D.; Maxwell, J.R. 1981. Land Systems Inventory for the Pacific Northwest Region and the Siuslaw National Forest. USDA Forest Service, Siuslaw National Forest. 22 p.

Hemstrom, M. A.; Logan, S. L. 1986. Plant association and management guide Siuslaw National Forest. R6-ECOL 220-1986a. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, OR. 121 p.

Johnsgard, G. A. 1963. Temperature and the water balance for Oregon weather stations. Agricultural Experiment Station Special Report 150, Oregon State University, Corvallis, OR.

Perry, D. A. 1984. Predicting response to precommercial thinning on the Mapleton District of the Siulsaw National Forest. Department of Forest Science, Oregon State University, Corvallis, OR. 30 p. Unpublished report.

Wagner, R. G.; Radosevich, S. R. 1987. Interspecific competition indices for vegetation management decisions in young Douglas-fir stands on the Siuslaw National Forest: Report No. 1. Department of Forest Science, Oregon State University, Corvallis, OR. 108 p. Unpublished report.

Waring, R. H.; Franklin, J. F. 1979. The evergreen coniferous forests of the Pacific Northwest. Science 204: 1380-1386.

TIMBER LAND CLASSIFICATION SYSTEM AND PROGRAMS DEVELOPED FROM HABITAT TYPING AND TIMBER STAND PROGNOSIS

Herbert S. Malany

ABSTRACT: Describes a land classification system developed using habitat types and a computer mapping system, stocking guides for precommercial thinning, and the diameter at which a tree is economically sound.

INTRODUCTION

I will be discussing the land classification system and mapping program developed by Boise Cascade Corporation using habitat types (h.t.), the stocking guides for precommercial thinning, and the DBH at which a tree should be harvested.

Before beginning to discuss each of these topics I will define the specific terms we coined for the topic.

For the land classification discussion there are two coined terms I need to explain:

1. "Productivity Class" (PC) is defined as a grouping of h.t.'s that have similiar growth potentials.

2. The "Stand" is our smallest land management unit and was defined by overlaying the logging method, the timber type, and the productivity class.

MAPPING PROJECT

In order to build the stand map we originally visualized, three map layers had to be developed. The maps were the h.t., timber type, and logging method.

The first one, the h.t. map, was completed over a 2-year period with a lot of help from Bob Steele. Our first challenge and Bob's was to teach our foresters:

1. To identify the different h.t.'s.

2. To use aerial photos and topographic maps to extend an identified h.t. to map additional areas without on-the-ground observation.

3. To determine the amount of ground sampling necessary to insure the h.t.'s were extended correctly.

The other two map layers we developed were:

1. Logging Method--The ownership was mapped by logging method or topography. Ground less than 35 percent topographic slope was classified as skidder ground, slopes between 35 percent and 55 percent were called tractor, and all lands over 55 percent were classified as cable or helicopter logging.

2. Timber Type--Standard terms for timber types were used, but we developed definitions to fit our stand structure. For example, to be classified as large sawtimber, the stand had to average 60 square feet of basal area over 20 inches DBH.

The first project after the field mapping was completed was delineating the ownership into stands or management areas based on habitat type, timber type, and logging method.

Our original definition for a stand was to have the h.t. map as the base layer and overlay with the timber type and logging map. With the completion of the h.t. mapping, it was readily apparent the 24 h.t.'s would have divided the ownership into thousands of map islands. Then when the timber type and logging layer were added to the h.t. layer, the number of stands this definition would have identified would have been both astronomical and unmanageable.

While the mapping was going on, the diameter growth coefficients for Prognosis (Stage 1973) were being developed by Chuck Hatch and Al Stage for the major h.t.'s in southwest Idaho to enable Prognosis to predict the growth rates for our geographic and climatic area.

To use Prognosis in southern Idaho, it was necessary to develop statistically sound coefficients for diameter growth for the h.t.'s found in the area. To get enough sample plots, we had to first h.t. the Continuous Forest Inventory (CFI) plots on Boise Cascade's land and then combine the data with diameter growth information from Boise, Challis, and Payette National Forests along with the Idaho Department of Lands. These coefficients became the Central Idaho version of Prognosis.

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Herbert S. Malany is Chief Region Forester, Boise Cascade Corporation, Emmett, ID.

For height growth, multipliers were developed for Prognosis so the model would predict the actual growth experienced between two measurements from the CFI plots on the Corporation's lands. To test the model, the growth predictions were compared to and adjusted when necessary to the actual diameter and height growth experienced on the different h.t.-timber type combinations from the Corporation's CFI plots.

With the development of the diameter growth coefficients and height multipliers for Prognosis completed, we found when running growth projections for the h.t.'s found on the Corporation's lands, the growth projections fell into four similiar groupings. This allowed us to develop the four Productivity Classes and reduce the stand combinations to a manageable number.

The 24 h.t.'s found on the Corporation's lands in southwestern Idaho were grouped in four productivity classes:

1. Wet Grand Fir--These h.t.'s are the best sites on the Corporation's land. Mountain maple is the major associated species.

2. Dry Grand Fir--These are the drier grand fir areas. Grand fir-huckleberry is the major h.t. of this series.

3. Wet Douglas-fir--These h.t.'s are the higher elevations and north slopes on Douglas-fir sites. Ninebark is the major associated species.

4. Dry Douglas-fir--These are the driest sites we have. Pinegrass is the major associated species.

When the h.t.'s were consolidated into the four productivity classes and overlaid with the timber type and logging maps, the stand map for the ownership was developed with a manageable number of stands. With 5 acres the minimum size stand, over 2,000 stands were defined. The stand combinations developed 31 identifiable management types--combinations of logging method, timber type, and productivity class.

With the completion of the development phase of the program, the coefficient for Prognosis and mapping, we began developing other parts for the Timber Management (TM) program.

The first project after mapping was completed was the development of an inventory for each of the stand combinations--tractor ground, small sawtimber, productivity class 3. The data for the inventory were limited to Boise Cascade's plots. The plots were classified by logging type, timber type, and productivity class to develop a yield table for each stand definition. Additional plots were added to stands with insufficient CFI plots for a sample. This information was also used to develop the yield tables for TimberRAM, FORPLAN, and the standing timber inventory.

IMPLEMENTING THE TM PLAN

Now, I will discuss two of the programs we developed to assist in implementing the TM Plan. The first program is the precommercial thinning (PCT) guidelines. The guidelines were developed for each logging method and productivity class and are designed as stocking guides where the minimum merchantable DBH and critical basal area are reached at the same time.

Before continuing, I will explain two terms used in the thinning guides:

1. Minimum Merchantable DBH--The DBH when the selling value for the lumber is great enough to pay for the costs of logging and manufacturing, and provide a normal profit. No value remains for stumpage.

2. Critical Basal Area (CBA)--The maximum basal area for optimum stocking and growth.

To develop the PCT guidelines, it was first necessary to determine the Minimum Merchantable DBH. This is the DBH where the tree generates only enough lumber selling value to pay the logging and manufacturing costs and provide a normal profit to the mill.

After the minimum DBH for each logging method was determined, the stocking levels needed to optimize growth per tree and per acre were developed for each productivity class. We found that the long-term growth predictions and the CBA for each of the Grand Fir Productivity Classes and the Douglas-fir Productivity Classes were similiar, so they were consolidated into two PCT guidelines.

By not harvesting below the minimum basal area, the leave stand is left stocked and growing at the maximum rate until the next entry.

The CBA's for the guidelines were determined by looking at three growth responses in Prognosis. The responses were the number of years after thinning before:

1. The reduction in basal area growth occurs.

2. The incremental cubic growth starts to decline.

3. A reduction in net cubic growth occurs.

The study was made using hypothetical stands of pure Douglas-fir (DF), ponderosa pine (PP), and grand fir (GF) thinned to 40, 60, 90, 120 and 150 square feet of basal area for each PC and then growing the stands in Prognosis for 10-year increments.

Prognosis runs were made to determine basal area when:

1. The stands were projected over time to determine the basal area at which the growth rate starts to decrease due to mortality. This exercise is helpful in determining the maximum basal area a stand can carry. However, it does not give the point at which stand volume growth is maximized (fig. 1).

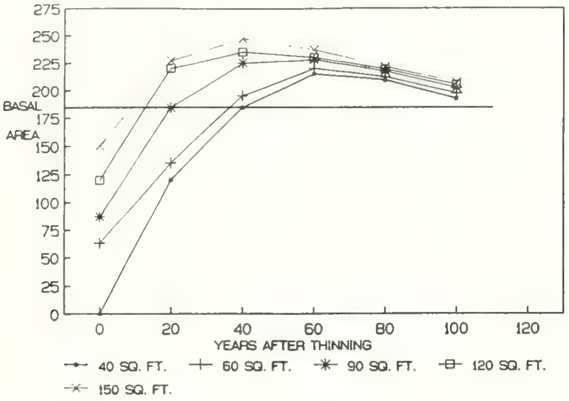

Figure 1--Reduction in basal area growth for five initial thinning densities.

2. Incremental growth is defined as total growth per period less mortality. The growth was determined by dividing the new growth for each period by 10 to determine the annual cubic foot growth for each period. This exercise shows the period at which growth is at the maximum (fig. 2).

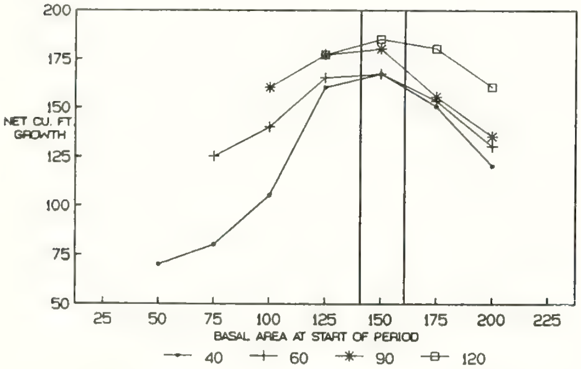

Figure 2--Reduction in incremental cubic foot growth.

3. This calculation is done by totaling the net growth to date and dividing by the corresponding years to determine when the net growth starts to decline. This calculation determines the Critical Basal Area or the density at which the cumulative growth rate declines (fig. 3).

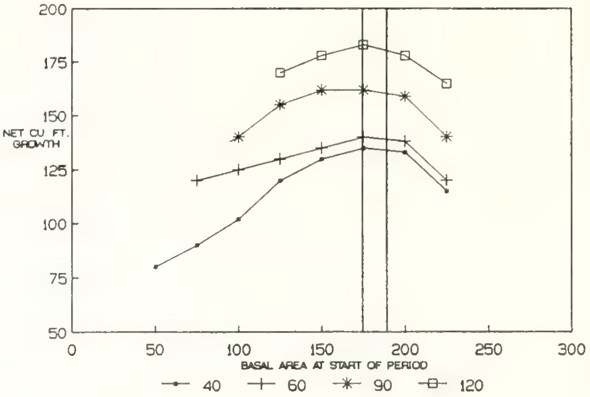

Figure 3--Reduction in average cubic foot growth.

The reduction in average growth generally occured 20 sq. ft. higher than the reduction in incremental net growth. This indicates that while the incremental growth is declining the stand continues to grow faster than average for a period of time. We decided to use the period when the reduction in net cubic growth occurs to determine the Critical Basal Area because the trees would be larger and more valuable.

After the minimum DBH and Critical Basal Area were determined, the stocking level for each logging type was an easy calculation based on the minimum merchantable DBH, annual basal area growth, years to next entry, and the Critical Basal Area.

The Critical Basal Area and the minimum basal area from the PCT study were used in the development of our marking guides.

TARGET DBH

The last study I will discuss is the development of the "Target DBH".

The definition for the Target DBH is the DBH where the interest rate the tree is returning stops decreasing. This is the diameter at which a tree should be harvested unless it is needed for silviculture purposes.

To arrive at the Target DBH Growth, the average crown ratio and height for the dominant and codominant trees were calculated for PP, DF and GF by diameter class and PC using data from the CFI plots. The data sets were run in Prognosis to determine the number of years it takes a tree to increase 1 inch in diameter (fig. 4).

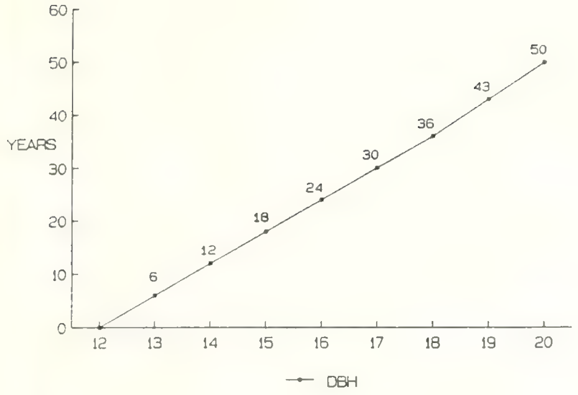

Figure 4--Target DBH growth.

Then the average tree size and the piece size for each diameter class and species were developed from Prognosis. The piece size information was used to determine the logging cost, which was subtracted from a log purchase price to determine the stumpage value for each DBH class (fig. 5).

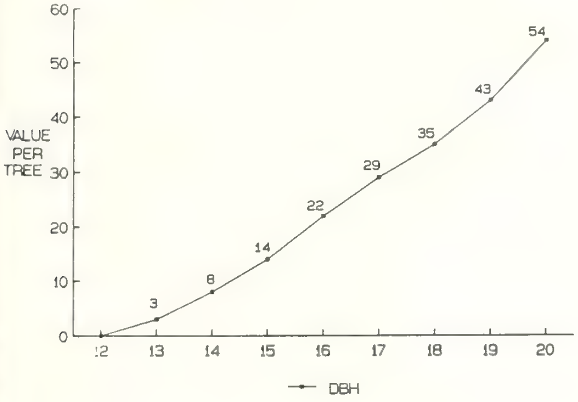

Figure 5--Stumpage value by DBH.

A periodic annual percent of return was calculated by species and logging type. The periodic return shows the diameter at which the annual percent of return in value tends to level out. The percent of interest is based on the tree value at the beginning DBH, the time required to grow to the next larger DBH, and the tree value at the larger (ending) DBH (fig. 6).

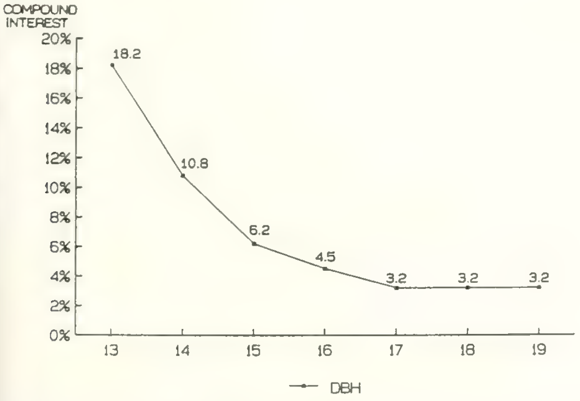

Figure 6--Periodic annual percentage return by tree.

Finally, a cumulative annual interest rate was calculated by species and logging type for each DBH (fig. 7). This percentage is based on total tree age, with a $.01 value at age zero, and the assumption that trees reach 12 inches DBH at age 60 on PC 1. This calculation shows the cummulative annual return by diameter class and the DBH at which the accumulative compounding interest rate stops declining.

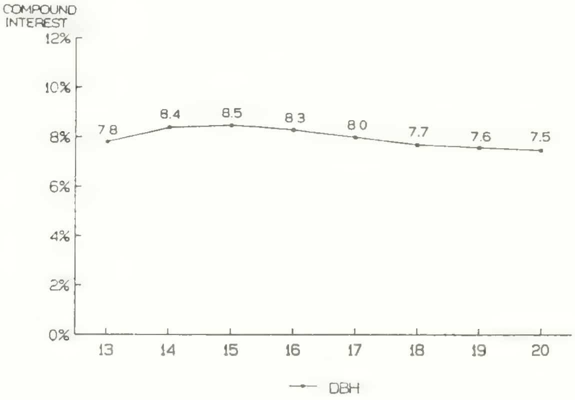

Figure 7--Cumulative annual percentage return on tree value by DBH.

The periodic and cumulative interest rates tended to level out at 17 or 18 inches DBH for all species and logging types, thus determining the target DBH.

LONG-TERM EFFECTS

Briefly, another project using h.t.'s and Prognosis was to determine the long-term effects of various silvicultural treatments. We made various studies with TimberRAM and FORPLAN to determine the best treatment alternatives for our stands. Clearcutting vs. seed tree vs. shelterwood vs. selective cutting were compared against each other to determine the most cost-effective way to manage the forest.

The conclusion was to stay with the selective systems whenever possible, that a limited amount of clearcutting and planting was necessary in some stand types, and the PCT thinning was desirable in a limited number of stands.

CONCLUSIONS

In conclusion, after all the harvesting, data gathering, Prognosis runs, studies, and observing the results of a mixture of silviculture treatments over the last 20 years in the ponderosa pine-mixed conifer forests of southwestern Idaho, I think:

1. Foresters are in much too big a hurry to reach that "managed stand in the sky" today by attempting to convert a 70- to 200-year old wild stand to an idealistic managed stand in one entry. On the silviculture side of the ledger, the result is overcutting on the initial entry with the

associated problems--excessive logging damage to the leave stand caused by the heavy cut, sunscald, blowdown, brush invasion, and damage to the watershed and big game habitat. On the political side is disapproval of the results by the public and other specialists and credibility about our ability to manage forests. On the economic side of the ledger, the owner is faced with a triple jeopardy of:

A. Paying a higher logging cost to harvest sub-economic trees (thrifty growing stock with a DBH of 16 inches or less).

B. Receiving lower stumpage from the mill because the logs are smaller and lower in value.

C. Waiting longer for the next economic return because the next entry (the 10- to 16-inch trees) were harvested today.

2. The foresters are not taught to manage the total forest, only to manage individual stands. The stand receiving the treatment is silvicultured to death. Subeconomic thrifty growing stock, which is included in the allowable harvest volume, is cut to arrive at the "managed stand in the sky." Then valuable high-risk or diseased trees in the next stand are left to die.

3. That foresters are too impatient to wait for natural regeneration to occur. They rush to plant areas without allowing time for natural regeneration to become established. Stands in the pine and mixed conifer types will regenerate naturally when the basal area is 70 sq. ft. or less and thrifty seed trees remain.

The best silviculture prescriptions are the ones that yield the highest return to the landowner today and minimize post-harvest silviculture prescriptions to treatments that are truly cost effective or are needed to control insects and diseases. In the stands of southwestern Idaho, this is easily accomplished by using common sense and prescribing practices that remove the larger diameter, economically mature trees, leaving the thrifty 10- to 16-inch trees for future harvests.

REFERENCE

Stage, Albert R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

BIOGEOCLIMATIC CLASSIFICATION--THE SYSTEM AND ITS APPLICATION

Del Meidinger and Andy MacKinnon

ABSTRACT: Resource managers in British Columbia commonly use a system of ecological classification called the Biogeoclimatic Classification (BGC) system. The system has been further developed and implemented by the B.C. Forest Service over the last 10 years; most of the province has now been classified. The BGC system is a hierarchical classification system with three levels of integration: local (vegetation and site classifications); regional (zonal or climatic classification); and chronological. Foresters primarily use the units of the regional (biogeoclimatic units: zone, subzone variant) and local (site units: site association, site series, site type) levels. Soil moisture and nutrient regimes are used to classify site units within biogeoclimatic units, using maps and field guides developed in each Forest Region. Interpretations provided for site units assist foresters in developing management prescriptions.

INTRODUCTION

Ecosystem classification in British Columbia follows the biogeoclimatic system. The classification provides foresters and other resource managers with a common framework for ecological management of forests and rangelands. Over the past decade, the classification system has become firmly entrenched in forest management and is used as well by wildlife, range, and parks managers. This paper will deal primarily with the use of the system in forest management.

Ecosystem studies carried out from 1950-1975 by Dr. V.J. Krajina and his students at the University of British Columbia resulted in the development of the Biogeoclimatic Classification (BGC) system (e.g., Beil and others 1976; Krajina 1965). The Forest Service adopted this system in 1975 and embarked on a province-wide program to produce an ecosystem classification that could be used at an operational scale. Many modifications to Krajina's system have been made over the years (Pojar 1983) - the most recent account of the system is provided by Pojar and others (1987) and is summarized here.

The classification of British Columbia has proved an immense undertaking for a number of reasons. The province of B.C. consists of about 30 million hectares dissected by a series of northwest-southeast trending mountain ranges; much of the area is inaccessable except by helicopter. The landbase is divided for management purposes into six Forest Regions. Ecosystem studies have been carried out primarily by research staff in the six Forest Regions with some provincial coordination. To date approximately 250 man-years have been invested in the project. Most of the sampling has been completed and operational maps and reports are available for most of the province. These maps and reports are presently in use by a broad spectrum of resource managers as information sources and as aids to decision-making.

Regional classifications are presently being correlated to produce a truly provincial classification. The data are being analyzed from a broader perspective with the result that many classification units are being merged--very similar ecosystems in different Forest Regions will have the same name, code, and interpretations. The results of this provincial correlation will become operationally apparent over the next few years.

PRINCIPLES OF BIOGEOCLIMATIC CLASSIFICATION

The BGC system organizes ecosystems at three levels of integration - local, regional, and chronological - with the intention of showing the relationships among ecosystems in form, space, and time. The local level organizes ecosystems according to their similarities in form, i.e., the structure and composition of their vegetation and physical environment. This

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Del Meidinger is Provincial Ecology Correlator, Research Branch, British Columbia Ministry of Forests and Lands, Victoria, B.C., Canada; Andy MacKinnon is Ecologist, Forest Sciences Section, Prince George Forest Region, British Columbia Ministry of Forests and Lands, Prince George, B.C., Canada.

is done by vegetation and site classifications (fig. 1) resulting in vegetation and site units. At the regional level, the vegetation on "zonal" sites is used to infer the regional climate; this zonal or climatic classification defines biogeoclimatic units. The chronological level is used to organize ecosystems according to site-specific chronosequences by arranging the vegetation units recognized for a particular site unit according to site history and successional status.

For practical purposes, a forester need only be concerned with the zonal and site classifications; the vegetation classification, however, is integral to developing both of these. Vegetation is emphasized because it is considered to be the best integrator of the combined influence of a variety of environmental factors affecting the site, and because differentiating floristic criteria can be determined. Vegetation units are floristically uniform classes of plant communities in the sense of the Braun-Blanquet approach (Westhoff and van der Maarel 1980). They are arranged in a phytosociological hierarchy where the plant association is the basic unit; alliances, orders, and classes are groups of associations, and subassociations are divisions of an association (table 1). To facilitate both classification and indication of environment, the Braun-Blanquet approach uses species with relatively narrow ecological amplitudes. Such species are 'diagnostic'; a group of them constitute a 'diagnostic combination of species' (DCS). The DCS is exclusive to a given vegetation unit and therefore is used as the sole differentia at the vegetation level. The DCS usually requires at least one differential-species (see table 1 and Pojar and others 1987). Determination of diagnostic values and combinations of species involves tabular comparisons and the criteria of table 1; see Pojar and others (1987) for examples.

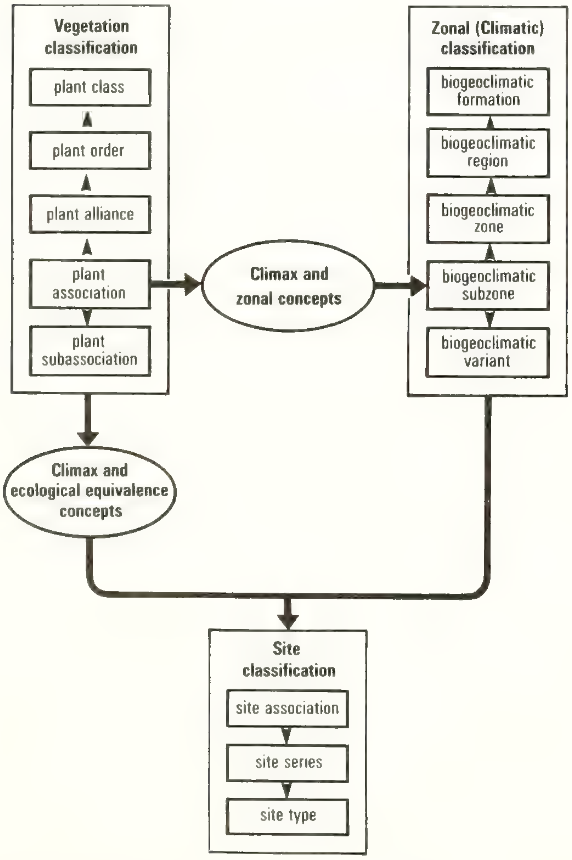


Figure 1--Categories and relationships of vegetation, zonal, and site classifications.

In B.C., the vegetation classification is presently being developed for late seral to climax ecosystems and is being used to correlate the classifications of the different Forest Regions. As early seral vegetation is sampled, it too will be classified and then organized, using the site classification, into site-specific chronosequences.

Biogeoclimatic units are the result of zonal (climatic) classification and represent classes of ecosystems under the influence of the same regional climate. Again, there is a hierarchy of units, with the biogeoclimatic subzone as the basic unit (table 1). A subzone is recognized as having a distinct climax (or near-climax) plant association on "zonal" sites. Zonal sites are intermediate in moisture and nutrients and are considered to reflect the influence of climate more strongly than other sites (e.g., Sukachev and Dylis 1964); therefore, they are the best reference sites to compare climate using climax vegetation. Subzones are grouped into zones and divided into variants.

The Sub-Boreal Spruce (SBS) zone, for example, represents an area of about 170,000 km^2 in central British Columbia, characterized by a continental climate with seasonal extremes of temperature, relatively short summers, and relatively low annual precipitation (Meidinger and Pojar 1983). Zonal sites within the SBS are characterized by climax forests of hybrid white spruce (*Picea engelmannii* X *P. glauca*), often in combination with subalpine fir (*Abies lasiocarpa*). Within the SBS zone, more regional climatic differences are evident: for instance, total annual precipitation ranges from 472 mm in the rainshadow of the Coast Mountains to 1233 mm in the foothills of the Rocky Mountains (McLeod and Meidinger 1986). These climatic differences are reflected in the development of different zonal, or climatic, ecosystems on zonal sites. Biogeoclimatic zones are divided into subzones based on the geographical extent of a particular zonal ecosystem. For example, on zonal sites in the relatively dry SBSe subzone, the climax plant community has a canopy of lodgepole pine (*Pinus contorta* var. *latifolia*) and hybrid white spruce, a shrub layer dominated by black huckleberry (*Vaccinium membranaceum*), and a herb layer characterized by bunchberry (*Cornus canadensis*). The zonal ecosystem of the moister SBSj subzone has more hybrid white spruce and subalpine fir in the canopy, black twinberry (*Lonicera involucrata*) in the shrub layer, and the excellent moist site indicator species, oak fern (*Gymnocarpium dryopteris*), in the herb layer;

the very wet SBSf subzone features the wet site indicator, devil's club (*Oplopanax horridum*), as the predominant shrub on its zonal sites. Subzones can be further divided into variants, based on finer differences in regional climate; the SBSe has been divided into western (SBSe1) and eastern (SBSe2) variants. The name "SBSe2" thus denotes the Sub-Boreal Spruce Zone (SBS), Moist Cool Central Subzone (e), Fraser Basin Variant (2).

Site units represent groups of sites (or ecosystems), regardless of present vegetation, that have the same, or equivalent, environmental properties and potential vegetation. The basic

Table 1--Synopsis of levels and categories of biogeoclimatic classification

Category	Differentia	Example
	Vegetation classification	
Class	exclusive DCS[1]	*Picea glauca* x *engelmannii*
Order	exclusive DCS	*Picea*-*Vaccinium*
Alliance	exclusive DCS	*Picea*-*Vaccinium*
Association	exclusive DCS	*Picea*-*Vaccinium*-*Viburnum*
Subassociation	exclusive DCS or non-exclusive DCS with 2 or more species	*Picea*-*Vaccinium*-*Viburnum*, *Rubus*(*parviflorus*)
	Zonal classification	
Formation	climatic group (Koppen/Trewartha)	Microthermal Coniferous Forest
Region	climatic type (Koppen/Trewartha); DCS derived from zonal and non-zonal climax ecosystems	Canadian Boreal Forest
Zone	zonal plant order (DCS derived from zonal climax ecosystems)	Sub-Boreal Spruce (SBS)
Subzone	zonal plant association (DCS derived from zonal climax ecosystems)	Moist Cool Central SBS (SBSe)
Variant	zonal plant subassociation (exclusive or non-exclusive DCS derived from zonal climax ecosystems)	Fraser Basin SBSe (SBSe2)
	Site classification	
Association	range of biogeoclimatic subzones or variants, soil moisture regimes, soil nutrient regimes, and if appropriate, an additional environmental factor or property controlling vegetation of the parent plant association	*Picea*-*Vaccinium*-*Viburnum*
Series	biogeoclimatic subzone or variant	SBSe2: *Picea*-*Vaccinium*-*Viburnum*
Type	one or more factors or properties that are identified as the major source of edaphic variation within the site association	SBSe2: *Picea*-*Vaccinium*-*Viburnum*/ Sandy

[1] DCS = diagnostic combination of species; must include at least one differential- or dominant differential-species.

Differential (d): species that is clearly associated with more than one unit in a hierarchy; presence class ⩾III and at least two presence classes greater than in other units of the same category and circumscription.

Dominant differential (dd): species that does not meet the presence criteria above but shows clear dominance in more than one unit in a hierarchy; presence class ⩾III, mean species significance ⩾5 and two or more significance classes greater than in other units of the same category and circumscription.

Presence classes as percent of frequency: I=0-20, II=21-40, III=41-60, IV=61-80, V=81-100.
Species significance classes and percent cover: +=0.1-0.3, 1=0.4-1.0, 2=1.1-2.2, 3=2.3-5.0, 4=5.1-10.0, 5=10.1-20.0, 6=20.1-33.0, 7=33.1-50.0, 8=50.1-75.0, 9=75.1-100.

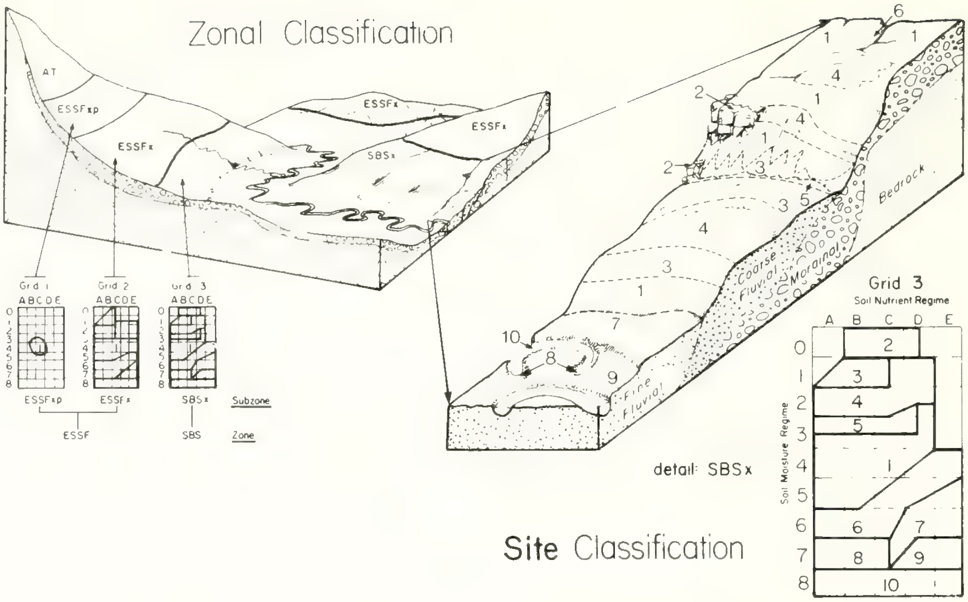


Figure 2--Schematic relationships between zonal and site classifications. AT, ESSF, and SBS are abbreviations for the Alpine Tundra, Engelmann Spruce - Subalpine Fir, and Sub-Boreal Spruce zones, respectively.

category in site classification is the site association; series and types are divisions of associations (table 1). The site association is equivalent to the habitat type (Daubenmire 1968). The limits of a site association are the same as those of the parent plant association - in other words, all land areas capable of producing vegetation belonging to the same plant association at climax are included in a single site association. The vegetation potential of a site association can be described in terms of all seral and the climax plant community that may occur on the site. The site association is characterized, however, by a combination of climate, soil moisture and nutrient regime, and, if appropriate, by an additional environmental factor or property strongly influencing the development of the parent plant association. For example, two site associations may occur in the same climate, and on sites with the same range of soil moisture and nutrient regime, but one may be subject to periodic flooding, and the other to temporary seepage, resulting in two different floristic assemblages distinguishable as plant associations.

A site association may contain ecosystems from several different climates and so be quite variable in actual site conditions. Dividing the association into site series produces site units that are climatically, and therefore usually edaphically, more uniform and more predictable in their response to management. A site series is equivalent to the ecosystem association of previous accounts (e.g., Pojar 1983).

Site series are then partitioned into site types according to one or more (usually many) edaphic properties thought to affect ecosystem response to management. This produces the most edaphically consistent classes of ecosystems. Site types reflect the compensating effects of site conditions within a uniform climate in producing similar vegetation. Site types represent ecosystem units that are uniform in the largest number of environmental characteristics.

The site association is named after the parent plant association (table 1). Site series are named by prefixing the name of the site association with the symbol for the biogeoclimatic subzone or variant; the site type consists of the name of the site series modified by one of the soil and landform characteristics.

SITE IDENTIFICATION

Figure 2 displays the relationship between the zonal and site classifications on a segment of a hypothetical landscape. One of the most important aspects of applying a site classification is correct identification of the classification units. Sites can be mapped, but province-wide mapping at an operational scale (i.e., 1:2,000 - 20,000) is not feasible. Instead, a variety of tools are provided to assist in identification of site units in the field. Users are provided with small-scale biogeoclimatic maps, keys, descriptive tables of characteristic understory vegetation and environmental features, slope position diagrams, edatopic grids, and guides to plant identification. Forest management interpretations accompanying each unit are used to develop a site prescription.

The first step in site identification is determining the biogeoclimatic unit. Biogeoclimatic maps at scales of 1:100,000 to 1:600,000, depending on the area, are available for the entire province (e.g., McLeod and Meidinger 1986; Nuszdorfer and others 1985). In areas near map boundaries, it is prudent to confirm the biogeoclimatic unit by checking certain habitat and floristic features with tables of information provided in the appropriate classification manual. These may be general features of the subzone or variant, or specific features of the zonal ecosystems.

Classification reports or handbooks are used to identify the site units in each subzone or variant. The organization of these guides, and the information presented, depends on the preference of the authors. All reports, though, contain an edatopic grid for each biogeoclimatic unit. The edatopic grid (fig. 3) displays the site units over a grid of relative (within the subzone or variant) soil moisture and nutrient regime classes. Soil moisture and nutrient regimes (Pojar and others 1987) can be determined using keys or tables (e.g., Green and others 1984; Lewis and others 1986) by assessing certain environmental features.

Soil and site factors used to determine soil moisture and nutrient regime include slope position, slope gradient and aspect, soil texture and coarse fragments, humus form and depth, organic matter content, depth to water table, presence of mottling, rooting depth, and parent materials. These factors have been selected as having the greatest influence on, or relation to, soil moisture and nutrient regime, and they can be assessed quickly and accurately with moderate training.

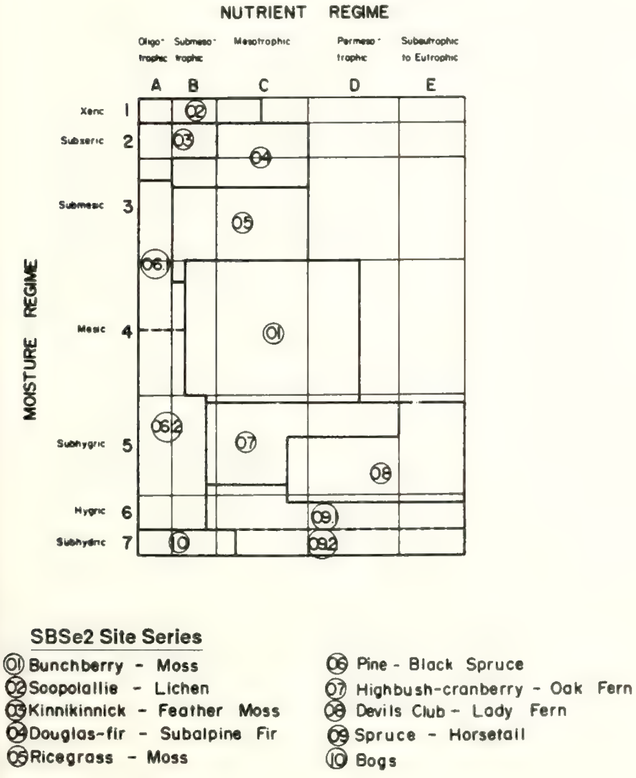


Figure 3--Edaptopic grid of ecological moisture and nutrient regime for the SBSe2 variant.

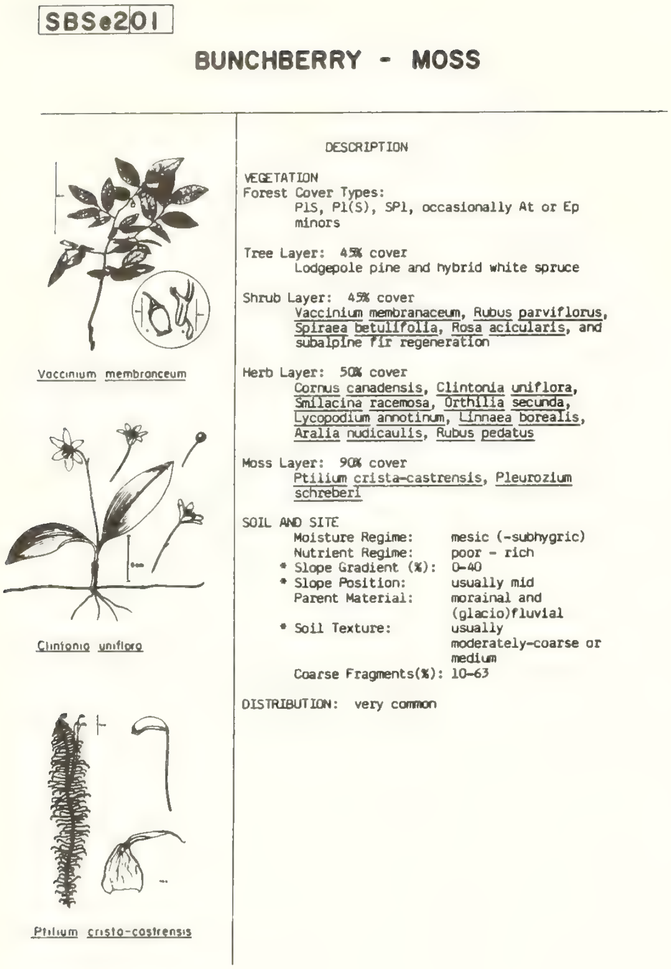
Presence and abundance (percent cover) of the plant species present on each ecosystem are noted and compared to the lists given for each site unit. Though vegetation is an extremely useful indicator of site conditions in mature forests, caution must be exercised in assessing more disturbed sites.

After assessing moisture and nutrient regimes, a site unit is determined from the grid and then confirmed by using keys to the site units, descriptive tables of characteristic understory vegetation and environmental features, and/or slope position diagrams. Keys utilize both vegetation and site features (e.g., Cariboo Forest Region 1987; DeLong and others 1987; Klinka and Krajina 1986; Lewis and others 1986).

Descriptive tables may be brief and limited to one or two pages per biogeoclimatic unit (e.g., Cariboo Forest Region 1987; Lloyd 1984) or more detailed and consisting of one page per site unit (e.g., Houseknecht and others 1986; MacKinnon and McLeod 1986). Slope position diagrams are often used to depict the location of the site units on the landscape in relation to slope position, aspect, and parent material (e.g., Mitchell and others 1981; Utzig and others 1986).

Site (ecosystem) units are given a symbol to allow for coding into databases. The symbol for a site series is appended after the biogeoclimatic code and separated by a slash; SBSe2/01 is a site series in the SBSe2 variant.

To illustrate the process of site identification in the BGC system, consider the SBSe2 variant. A user would first consult the appropriate 1:250,000 biogeoclimatic unit map, from which it could be determined that the area to be classified lies in the SBSe2. The user would then take the appropriate field guide (DeLong and others 1987) to the site to be classified. After noting various environmental and vegetational characteristics, the user would turn to the edatopic grid for the SBSe2 (fig. 3). Ten site series within the SBSe2 are displayed on the grid; by choosing the appropriate moisture regime (y-axis) and nutrient regime (x-axis) one arrives at the number of a site series. If the moisture and nutrient regimes were both judged to be average (mesic, mesotrophic), the grid would indicate the SBSe2/01 site series. The user can then turn to a description of the site series (fig. 4) to confirm or reject the identification. The field guide also presents other aids to site unit identification, including keys and slope position diagrams.


Vaccinium membronceum
Clintonio unifloro
Ptilium cristo-costrensis

SBSe2 01

BUNCHBERRY - MOSS

DESCRIPTION

VEGETATION
Forest Cover Types:
PlS, Pl(S), SPl, occasionally At or Ep minors

Tree Layer: 45% cover
Lodgepole pine and hybrid white spruce

Shrub Layer: 45% cover
Vaccinium membranaceum, Rubus parviflorus, Spiraea betulifolia, Rosa acicularis, and subalpine fir regeneration

Herb Layer: 50% cover
Cornus canadensis, Clintonia uniflora, Smilacina racemosa, Orthilia secunda, Lycopodium annotinum, Linnaea borealis, Aralia nudicaulis, Rubus pedatus

Moss Layer: 90% cover
Ptilium crista-castrensis, Pleurozium schreberi

SOIL AND SITE

Moisture Regime:	mesic (-subhygric)
Nutrient Regime:	poor - rich
* Slope Gradient (%):	0-40
* Slope Position:	usually mid
Parent Material:	morainal and (glacio)fluvial
* Soil Texture:	usually moderately-coarse or medium
Coarse Fragments(%):	10-63

DISTRIBUTION: very common

Figure 4--Description of the SBSe2/01 site series.

SITE INTERPRETATION

The BGC system provides a framework for presenting intepretations for forest management that suggest treatments most suited to a particular group of ecosystems. The interpretations are based on an understanding of the structure and function of the ecosystems, limiting factors, constraints, capabilities, accumulated knowledge of the reaction of a particular site unit to proposed manipulations, and social (ethical) objectives such as maintaining site productivity or sustained yield.

Interpretions are determined for the conceptualized ecosytems, and they include limited management objectives and economic considerations. Prescriptions, on the other hand, are developed using the interpretations (Lewis 1987); they are specific to an individual site and stand, and they are determined after consideration of many management and economic factors.

Interpretations are primarily for silviculture and include tree species selection, site preparation, regeneration method, stocking standards and stand tending considerations, among others (e.g., Cariboo Forest Region 1987; Green and others 1985; DeLong and others 1987; Lewis 1987, and others 1986; Mitchell and others 1981; Utzig and others 1986). Engineering and range management interpretations are also made (e.g., Cariboo Forest Region 1987; Comeau and others 1982).

Two approaches have been taken to the presentation of these interpretations: multiple interpretations for a classification unit; and single interpretations for groupings of related classification units. Both approaches are valid and the utility of one over the other depends on the needs of the specific user group applying the interpretations.

To continue our previous example, forestry interpretations for the SBSe2/01 site series are presented in figure 5. After determining that the unit in the field is the SBSe2/01 site series, the user can then turn to the interpretations for that site unit for assistance in formulating a prescription for the site. In this case, it is suggested that the site be harvested by clearcutting; that site preparation consist of a light broadcast burn or drag scarification; that regeneration options include planting lodgepole pine or hybrid white spruce, or encouraging natural seeding in of lodgepole pine; that aspen suckering and mistletoe have been problems on this site series in the past; and that site productivity should allow production of spruce or pine sawlogs on a 70-year rotation.

Identification of the ecosystems comprising a proposed or treated block is required for all silviculture assessments on Crown forest land (Green 1985). Through the pre-harvest silviculture prescription process, the ecological characteristics of a block must be assessed, and all stages from harvesting to the free growing stand prescribed for component sites within a block.

SILVICULTURE INTERPRETATIONS

								Regeneration Options							Stand Tending	
								Natural		Artificial						
Logging Method	Brush Hazard	Other Constraints	Site Preparation	Species Select.	Regen. Delay	Time to Free Growing	% Canopy Removed	Species	Seedling /ha	Species	Shoot/ Root Ratio	Caliper (mm)	Height (cm)	Seedling /ha	Time of Thinning	Stems/ha after Thinning
clearcut	mod.	-mistletoe	-light drag scarify -mix humus with mineral soil or light broadcast burn (remove L horizon) -windrow & burn	Pl	3	5		Pl	1500	Pl	2.5/1	4	15	1500	15	1000
				Sx	1	5				Sx	2/1	5	22	1000		

TIMBER INTERPRETATIONS

Logging Method	% Slope	Seasonal Constraints	Recommended Harvesting System
clearcut	0-30	S or W	conventional
	31-40	S or W	medium cat

COMMENTS

I. Management Objectives:
- manage for sawlog on a 70 year rotation.

II. Silviculture Applications:
- do not accept advance Bl regeneration.
- conduct a Pl cone survey to see if enough seed is present to establish a natural Pl stand. If so, mechanically treat site.
- if cones are insufficient, plant Pl stock without site preparation.
- light drag scarify if logged in winter and cone crop survey indicates a good supply of seeds.
- windrow and burn if stand has 60% + component of Sx.
- thinning of over-dense Pl will need to be done only if a site inspection indicates the need for this treatment.

III. Silviculture Problems:
- aspen suckering can be a serious problem.
- mistletoe infestation may be high on these sites so a mistletoe clause should be written into the cutting permit to help reduce the impact of the disease on the future stand.

Figure 5--Forestry interpretations for the SBSe2/01 site series.

SUMMARY

Biogeoclimatic classification has been applied to a region of North America that has complex patterns of climate, topography, geology, physiographic history, soils and vegetation. The system has been implemented by the British Columbia Forest Service, and many resource managers now use the system. The BGC system is a hierarchical classification with three levels of integration -- the local, regional, and chronological. The zonal classification is at the regional level, the vegetation and site classifications at the local level. The chronological level of classification is developed by applying the vegetation classification to seral ecosystems and organizing the associations within the site classification (Pojar and others 1987).

A variety of tools are provided to assist foresters in identifying the site units and in developing their forest management prescriptions. The application of the system has resulted in an increased ecological awareness among practicing foresters and in improved forest management practices. Results of operational trials and research can be extrapolated to other areas more successfully within the framework provided by the classification. The opportunity now exists for foresters in British Columbia to practice forestry as "applied ecology".

REFERENCES

Beil, C.; Taylor, R.; Guppy, G. 1976. The biogeoclimatic zones of British Columbia. Davidsonia. 7: 45-55.

Cariboo Forest Region. 1987. A field guide for the identification and interpretation of ecosystems of the Cariboo Forest Region. Williams Lake, B.C.: B.C. Ministry of Forests and Lands. Author's Draft.

Comeau, P.; Comeau, M.; Utzig, G. 1982. A guide to plant indicators of moisture for southeastern British Columbia, with engineering interpretations. Land Management Handbook Number 5. Victoria, B.C.: B.C. Ministry of Forests. 119p.

Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. New York: Harper & Row. 300p.

DeLong, C.; Hope, G.; McLeod, A. 1987. A field guide for the identification and interpretation of ecosystems of the SBSe2 in the Prince George Forest Region. Prince George, B.C.: B.C. Ministry of Forests and Lands. 47p. Author's Draft.

Green, R. 1985. [In press]. Biogeoclimatic ecosystem classification and its application to silvicultural decision-making in British Columbia. 1985 Jasper IUFRO conference: Proceedings; Sault Ste. Marie, Ontario: Canadian Forestry Service, Great Lakes Forest Research Centre. 15p.

Green, R.N.; Courtin, P.J.; Klinka, K.; Slaco, R.J.; Ray, C.A. 1984. Site diagnosis, tree species selection and slashburning guidelines for the Vancouver Forest Region. Land Management Handbook Number 8. Victoria, B.C.: B.C. Ministry of Forests. 143p.

Houseknecht, S.; Haeussler, S.; Kokoshke, A.; Pojar, J.; Holmes, D.; Geisler, B.M.; Yole, D.; Clement, C. 1987. A field guide for identification and interpretation of the Interior Cedar - Hemlock Zone, Northwestern Transitional Subzone (ICHg), in the Prince Rupert Forest Region. Land Management Handbook Number 12. Victoria, B.C.: B.C. Ministry of Forests and Lands. 187p.

Klinka, K; Krajina, V.J. 1986. Ecosystems of the University of British Columbia Research Forest, Haney, B.C. Vancouver, B.C.: Faculty of Forestry, University of British Columbia. 123 p.

Krajina, V. 1965. Biogeoclimatic zones and classification of British Columbia. Ecology of Western North America. 1: 1-17.

Lewis, T. 1987. Biogeoclimatic ecosystem classification correlation project, interpretations and implementation phase, direction and strategy 1987-1990. Victoria, B.C.: B.C. Ministry of Forests and Lands. 50p. Unpublished report.

Lewis, T.; Pojar, J.; Holmes, D.; Trowbridge, R.; Coates, D. 1986. A field guide for identification and interpretation of the Sub-Boreal Spruce Zone in the Prince Rupert Forest Region. Land Management Handbook Number 10. Victoria, B.C.: B.C. Ministry of Forests. 102p.

Lloyd, D. (compiler). 1984. Identification and interpretation of ecosystem units in the North Thompson - Shuswap drainage basins. Kamloops, B.C.: B.C. Ministry of Forests. 76p. Author's Draft.

MacKinnon, A.; McLeod, A. 1986. A field guide for the identification and interpretation of ecosystems of the ESSFh3 in the Prince George Forest Region. Prince George, B.C.: B.C. Ministry of Forests. 33p. Author's Draft.

McLeod, A.J.; Meidinger, D.V. 1986. Biogeoclimatic units of the Prince George Forest Region. Victoria, B.C.: B.C. Ministry of Forests. 1:600,000 coloured map.

Meidinger, D.; Pojar, J. 1983. Sub-Boreal Spruce zone. In: Watts, S.B., ed. Forestry handbook for British Columbia. Vancouver, B.C.: The Forestry Undergraduate Society, Faculty of Forestry, University of British Columbia: 306-311.

Nuszdorfer, F.C.; Kassay, K.L.; Scagel, A.M. 1984. Biogeoclimatic subzones of the Vancouver Forest Region. Vancouver, B.C.: B.C. Ministry of Forests. 1:500,000 coloured map.

Pojar, J. (editor and compiler). 1983. Forest ecology. In: Watts, S.B., ed. Forestry handbook for British Columbia. Vancouver, B.C.: The Forestry Undergraduate Society, Faculty of Forestry, University of British Columbia: 221-318.

Pojar, J.; Klinka, K.; Meidinger, D.V. [In press]. Biogeoclimatic classification in British Columbia. Forest Ecology and Management. 21.

Sukachev, V.; Dylis, N. 1964. Fundamentals of forest biogeocoenology. Transl. by J.M. MacLennan (1968). Edinburgh and London: Oliver & Boyd. 672p.

Utzig, G.; Comeau, P.; Macdonald, D.; Ketcheson, M.; Braumandl, T.; Warner, A.; Still, G. 1986. A field guide for identification and interpretation of ecosystems in the Nelson Forest Region. Nelson, B.C.: B.C. Ministry of Forests. 77p. Author's Draft.

Westhoff, V.; Van der Maarel, E. 1980. The Braun-Blanquet approach. In: Whittaker, R.H., ed. Classification of plant communities. The Hague: Junk: 287-399.

TOWARD A USER-FRIENDLY ECOSYSTEM: MYTH OR MIRTH?

Edward F. Schlatterer

ABSTRACT: Classifications of vegetation are not yet refined enough by other environmental factors to adequately identify a usable potential. In most cases ecotones, alternative successional pathways, and early successional development have not been identified adequately enough to satisfy the needs of the users. Some of the traditional concepts of succession need to be reevaluated to adequately identify factors and mechanisms that contribute to the arrest of seral stages for long indeterminable periods, or to the development of new potentials. Classifications must be modified to satisfy the needs of the user for short-term predictions in early succession that can be used to make rational management decisions and minimize the risk of making wrong decisions.

INTRODUCTION

I am John Q. User. I am a resource manager. I deal with existing vegetation.

- Much of it is severely disturbed.
- Much of it has been disturbed over a long period of time by multiple disturbances.
- Some disturbances are long-term and some are short-term.
- Some disturbances are intermittent and some are continuous.
- Some disturbances are slight while others are severe.
- Exotic species are present in the vegetation.

I also deal with the land.

- Much of the soil, on the lands I deal with, has been disturbed.
- On much of the lands I deal with, soil has been lost.

I have some problems:

1. I need to be able to predict what the consequences are of managing the land and its vegetation in different ways. I need to know what the consequences will be next year, 5 years from now, 10 years from now, and 50 years from now.

2. I need to know the consequences of managing the land and its vegetation on every acre.

3. I need to know the consequences of managing the land and its vegetation for all the resources and users.

4. I need to know the risk of making a wrong decision, and the potential consequences of any wrong decision, in advance, so that I can display the degree of uncertainty of my decisions.

Now, here comes Jim Dan D. Classifier. He claims to have a solution to my problem. His solution is:

1. Use his key which contains the species and community characteristics to identify the potential and the characteristics of that potential he has described.

2. Use his classification to identify the potential natural vegetation on my sites and my problems will be over.

Sounds good, I will do it! At my next inventory plot I gather my inventory data as usual--land, soil, and vegetation characteristics. I take my vegetation data, and attempt to use Jim Dan D. Classifier's key and description.

Results:

1. The key leads me to two or more solutions as to what the potential might be.

2. The site of my inventory plot no longer contains an "A" horizon and part of the "B" horizon is missing.

3. My plot contains exotic species not included in the classification.

4. I do not know the nature and duration of the disturbances to the site.

5. I do not know the risk of making the wrong choice and misidentifying the potential.

6. The potential identified by Jim Dan D. Classifier could not possibly occur on my site in less than 100 years.

I am John Q. User, and I still have a problem! WHAT WENT WRONG?

Paper presented at the Symposium on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Edward F. Schlatterer is Ecologist, Range Management, U.S. Department of Agriculture, Forest Service, Washington, DC.

NEW DIRECTION

I would like to explore with you some directions we need to take to solve John Q. User's problems and make classifications more user friendly and more responsive to user needs.

All too often classifications are developed as an academic exercise with no particular user in mind, with the result that the classification is less than useful and sits on a shelf. Even when the classification is developed for a client, it fails to fulfill expectations. It cannot be systematically fitted in existing inventories, nor can it be applied to existing data, and it does not provide information needed for shorter periods than those necessary to reach potential or near potential. And, for all the reasons stated above for John Q. User, it fails to satisfy the need.

In a few instances, the Jim Dan D. Classifiers have been making serious attempts to satisfy the needs, but in all too many cases they have not. It is, in my opinion, a major failing that must be corrected if we expect to get a lot of good work into practical use. It is imperative that work be initiated in this area if we are to avoid criticism in implementing our Forest plans.

In the 9th Circuit Court of Appeals decision on water rights, the judge ruled that the Forest Service must be able to guarantee, in advance, that State Water Quality Standards will be met. It was not good enough that the procedures used complied with standards for best management practices that were previously established. In my opinion, this same kind of scrutiny and guarantee will be required for all management prescription whether they are water related or not. We will be required to predict in advance consequences of all our management actions, prove that long-term productivity will not be impaired, and most important, provide a measure of how confident we are in our predictions.

As an alternative to proving in advance that impairment will not result, or making a wrong choice, I believe we will be required to define the level of risk involved in each alternative and justify our decision if an alternative other than the lowest risk alternative is chosen.

In order to provide this kind of information, the Jim Dan D. Classifiers are going to have to provide more short-term information, more early successional information, and more information on alternative successional pathways together with the documentation the John Q. Users can use, understand, and display in a meaningful way. They are going to have to provide guidance for sites that occur in ecotones, for handling exotic species, for sites from which soil has been lost, for dealing with different geologic materials, for dealing with different soils or slope steepness or aspect.

In short, the job has just begun when a classification is produced. It is not the end, it is the beginning. It is a new beginning for Jim Dan D. Classifier. It is a challenge that must be taken up if vegetation classification is ever to take a meaningful place in land classification and management and be used as it should be, as a predictive tool. It is a challenge that must be met in an interdisciplinary fashion.

MULTIPLE COMPONENT NEEDS

Those of you who hold that the vegetation can be used as universal prediction tool, without input from other specialists, need to reassess your position and look at the reality of the current situation. Even the best classification used on landscapes with mostly potential or near potential vegetation can only successfully classify 60 or 70 percent of the landscape. It is only when other factors such as soils, geology, topography, slope, and aspect are incorporated (the exceptions if you will) that John Q. User can successfully classify all of his area. John Q. User has no other option, but to do something with the 30 or 40 percent of his area that he can't classify.

Data related to treatment response can only be successfully extrapolated to other like ecosystems. If the data that define the ecosystem are only based on a single component such as vegetation, they can only be successfully applied to other areas with the same vegetation potential and the same soil, geology, topography, slope, and aspect. Applying data from plots identified by one component, such as vegetation, can only lead to misapplication of results when applied to another site with different soils, geology, topography, slope, and aspect. Land capability identified by one component only, a single resource inventory, will be limited to that one component. Only when integrated components are identified, can a proper extrapolation be made. Integration of components is essential for John Q. User to have the answers for the complex management situations he encounters.

I would like to illustrate what I am talking about, "The dilemmas of the John Q. User's," and in particular the Forest Service John Q. User, in attempting to implement a Forest Plan prescription on a given area of ground.

The Forest Plan identifies a desired future condition of the Forest 50 years into the future. The implementation schedule usually deals with the first 10-year increment. John Q. User needs to know how much of what he is going to do this year, next year, and the year after, is contributing to that desired future Forest condition. He needs to know it with a comfortable degree of certainty.

There were certain basic assumptions that were made in the Forest Planning process. He needs to verify if they were correct or not. He must be certain that his project is consistent with the basic assumption over both the short term and the long term. How many of the classifications for vegetation that you have looked at lately provide this kind of information? Not many, if you have been looking at the same ones that I have recently. They are going to have to provide this kind of information in the future.

PROBLEMS

There are four basic problems that need to be addressed. First, there is a real problem of alternative successional pathways. There is a second problem of alteration of the potential as a result of a disturbance of application of a management prescription. Third, there is the problem of long-term arrest of succession in some stage of succession, other than potential. And fourth, there is the problem of multiple potentials within an identified plant association or habitat type. I would like to briefly address each of these problems.

Successional Pathway

Dr. Ben Norton of Utah State University wrote a rather interesting paper in 1981 for the National Academy of Sciences Symposium on Impacts of Grazing Intensity and Specialized Grazing Systems on Use and Values of Rangelands. Unfortunately, his paper was not included when the report was published in 1984. In his paper, Dr. Norton advanced an alternative model to the traditional rangeland model that has been used to display succession and condition on rangelands. It also has application to forest ecosystems.

Figure 1 is a redraft of a schematic diagram presented by Dr. Norton based on previous studies by others in South Africa with a few embellishments. The traditional view is that succession or retrogression of vegetation on rangelands follows the right-hand part of the diagram. This part of the graph..."relies on the validity of Clementsian succession, which assumes a kind of "relay floristics" in which successive communities are predictable from the microhabitat generated by their predecessors."

Alteration of Potential

There are many other ecologists who recognize alternative pathways of vegetation change. The reasons for alternative pathways are many, including variations in species occurrence from site to site, the age structure of the plant community when disturbed, different reproductive abilities of different species, different sprouting abilities of different variants of the same species, the kind of disturbance and its duration and intensity, soil differences, and many others.

The left-hand part of the figure illustrates succession to a new and different potential as a result of various disturbances and pressures on the site that break the chain and preclude succession according to what theory would suggest. Some disturbances can be severe enough to alter the potential of a site for the foreseeable future.

If you stop and think about it, there are many examples of altered potentials. They include:

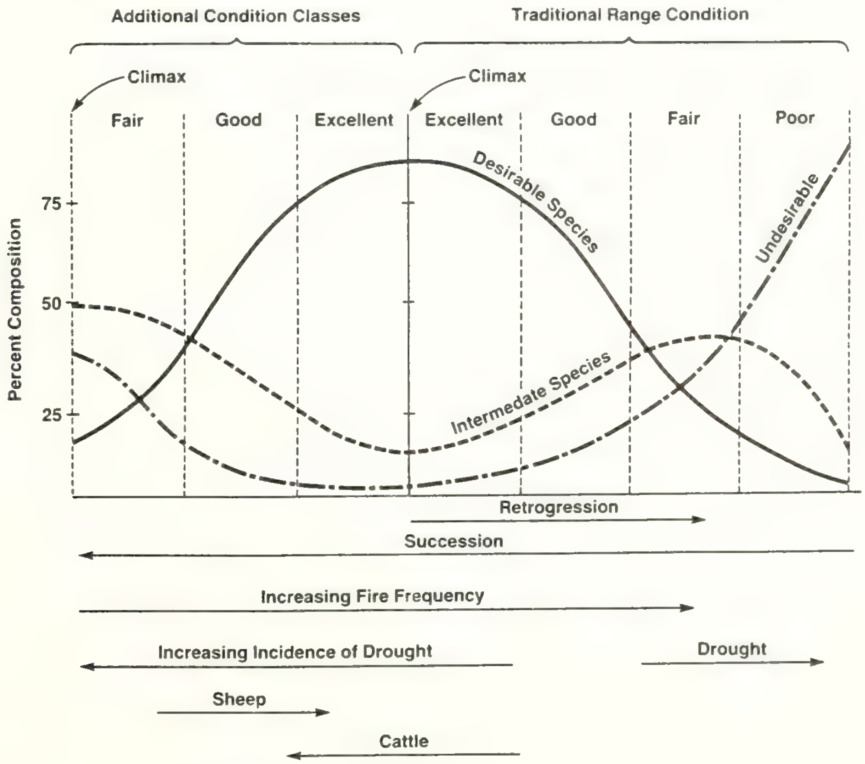


Figure 1--Modification of traditional U.S. concept of range condition to account for climax species composition being less desirable for livestock grazing than earlier successional stages.

the change from a bunchgrass-savannah to annual grasslands in California; self-perpetuating cheatgrass occupying sagebrush-bunchgrass sites in southern Idaho; the subalpine fir sites in and around Yellowstone National Park in a permanent lodgepole pine cover; chapparal occupying pine sites in southern California; and the elimination of the American chestnut from eastern hardwood sites. There are many other examples throughout the United States. Such permanent alterations of potential are even more common elsewhere in the world. If you have a chance, I strongly recommend reading a paper by R. Merton Love entitled "The Range-Natural Plant Communities or Modified Ecosystems?" printed in the Journal of the British Grassland Society, Volume 16, No. 2 in 1961.

After considerable thought about Dr. Love's paper and Dr. Norton's discussion and graph, I redrafted in figure 2 what I think better illustrates the complexity of alternative successional pathways, alteration of the potential as a result of disturbance and the arrest of succession at some stage other than the potential natural community for the site.

Long-Term Arrest

In this rather busy illustration, successional pathways are illustrated as the pages of a book radiating out from the book's backing, which represents the identified potential natural community of a site. In each case, depending on the kind of disturbance and its duration and intensity, retrogression and/or succession differs. The rate of succession may differ depending on any number of factors. Succession may be halted or recycled within a narrow range indefinitely at some point on the successional scale other than at the potential natural community of the site.

On the other hand, succession may follow normal Clementsian succession as it does in Great Plains grasslands. The mechanism and factors that contribute to or cause the alteration of the potential or arrest succession are almost totally unknown or at least poorly known. They are of vital importance, however, to the John Q. Users. The risk or the probability of their occurrence is also unknown and rarely factored into the management prescription when it is applied.

To add to the problem is long-time climatic change, and relatively short-duration change, that have occurred in the recent past. In the 10th century or thereabouts, there is evidence the Vikings landed in Greenland, Newfoundland, and perhaps as far south as Cape Cod. The evidence suggests that the climate was much milder then. By about 1300 AD a significant cooling occurred in the Northern Hemisphere which probably culminated in the Little Ice Age in the late 1700's. Since then we have had warming, then cooling, and now with the rise in carbon dioxide, we anticipate significant warming again.

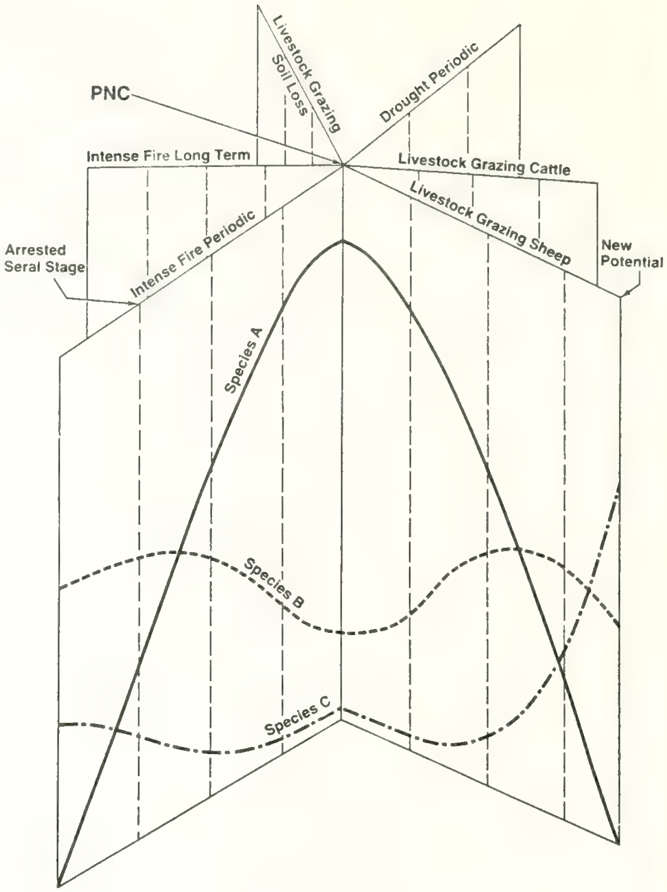


Figure 2--Alternative successional pathways.

Of course, not all communities are affected by such changes. But any community with a narrow margin of sensitivity or tolerance would be. I am not totally convinced, in light of past and potential climatic changes, of the utility of a habitat type classification that identifies a potential that takes 150 years to achieve for other than providing a framework end point and a historical perspective.

The John Q. Users are interested in change as a result of their management next year, in 5 years, in 10 years, and 50 years from now; and how their decisions contribute to the desired future condition of the Forest. They are also interested in the probable condition at the end of the rotation. Most rotation ages have been lowered to 80 or 90 years, and in some places such as the Southeast, to as little as 40 years. The few remaining stands that have weathered 200 to 1,000 years of climatic change and environmental hazards are extremely valuable from a reference stand point, but cannot be practically incorporated into the day-to-day management decisions.

I am going to sprinkle a few grains of salt on this graph to illustrate the problem of exotic and opportunistic species, which may be present at any stage of succession. The chance presence of such species in early succession may alter the path of succession or alter the final combination of species of the potential natural community of any altered potential or arrested seral stage. This problem is a very real one throughout the United States. I can illustrate this problem by asking you how many sites you know of in the State of Idaho that contain no cheatgrass. The list of naturalized exotic species of all kinds is almost unlimited, but the problem is very real and serious for John Q. User.

Multiple Potentials

To illustrate the problem of multiple potentials within a plant association or habitat type, I further modified figure 2 and came up with figure 3. Many association and habitat type descriptions define a vegetation potential so broad that it overlaps many differences in soils, geology, topography, slope, and aspect. When the site is disturbed, it starts from somewhere within the oval, depending on the particular combination of environmental factors and may or may not follow the successional pathway for a particular disturbance as illustrated.

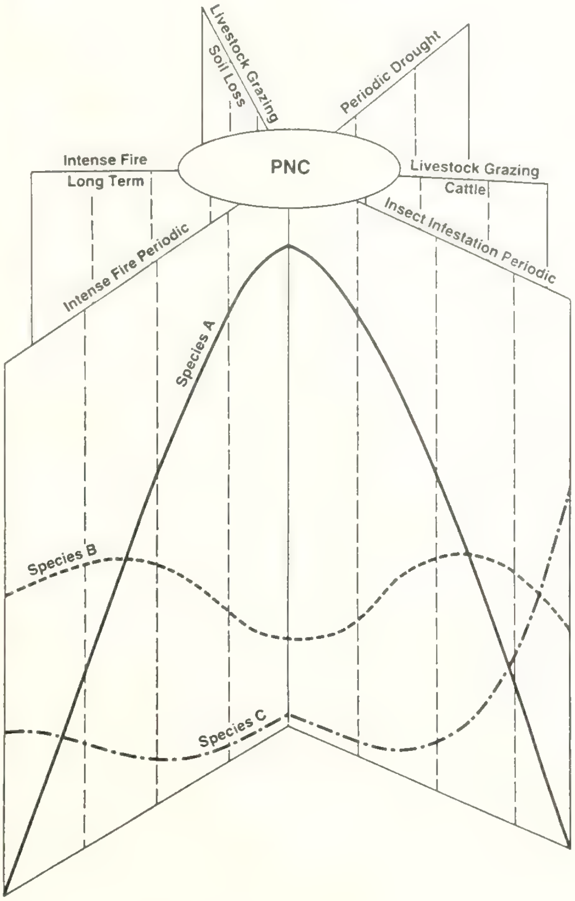


Figure 3--Alternative successional pathways.

More often than not, a new page of the model must be added because the particular environmental combination of the site causes important differences in the successional pathway. A totally new arrested seral stage may result, or a totally new potential, if the disturbance is severe enough. If the succession progresses back to the original potential natural community, that potential may have to be redefined as a new habitat type because of the altered successional pathway that resulted following disturbance and the realization that site potential makes a difference in the management options available.

Some of the refinements of previous classifications, which are and have been taking place recently, are undoubtedly the result of the realization of these kinds of differences.

SUMMARY

In summary, a lot of good work has been done by the Jim Dan D. Classifiers. Some of it is not in use by the John Q. Users for reasons I have explained.

Some classifications are not refined enough by site conditions other than vegetation to adequately identify a usable potential. In most cases ecotones, alternative successional pathways, and early successional development have not been identified adequately enough to satisfy the needs of the John Q. Users. The risk of making a wrong decision is unknown. And finally, some of the traditional concepts of succession need to be reevaluated to adequately identify factors and mechanisms that contribute to the arrest of seral stages for long indeterminable periods, or to the development of new potentials.

The bottom line is that vegetation classifications are not yet user friendly, nor will they be, until the Jim Dan D. Classifiers "get down and dirty" and immerse themselves in John Q. User's problems. They must satisfy needs for short-term early successional predictions that can be used to make rational management decisions and minimize risks of making wrong decisions. In many areas of the West, the easy part of association and habitat type classification is over. What remains is to make the classifications user friendly to all resource users and accommodate the problems I have identified. I don't have an easy answer for getting the job done. I do know it will require a refocusing of effort and a commitment by decision makers. The speed with which it will happen will depend on the severity and frequency of problems we have in implementing Forest Plans and scrutiny we receive from the public.

VEGETATION CLASSIFICATION -- PROBLEMS, PRINCIPLES, AND PROPOSALS

Kristen R. Eshelman, Robert E. Wagner, and Glen M. Secrist

ABSTRACT: There are a number of vegetation classification systems. All seem to be based on different concepts or perspectives. Most provide resource managers with useful, yet often incomparable information. Current philosophies on classification, succession, and condition reporting are discussed from a Bureau of Land Management perspective. A classification method is proposed which would result in improved resource management and condition reporting.

INTRODUCTION

Have people encountered delays or difficulties in arriving at this symposium? Have the American people experienced delays, cancelled flights, lost luggage, near misses, poor meals, and/or exorbitant fares in the last year? Have we benefitted from fare reductions, increased flights, or the merging of inefficient airlines? The answers to these questions are obviously yes.

Within the last 100 years ecologists have presented a number of classification systems to their peers. They have been based on historical, present, and potential vegetation (Bailey 1978; Paysen and others 1980; Allen 1987; Kenner and Allred 1962). Agencies, through resource managers, have adopted their own preferences and suffered the difficulty of not being able to share or compare information without using two different techniques or concepts on the same site(s). Countless dollars have been spent and hours wasted duplicating efforts in an attempt to gain a common understanding of vegetation classification. Inventories have been boxed and stored because a new classification system outdated the old system and its associated procedures.

POTENTIAL VEGETATION VERSUS PRESENT VEGETATION

Vegetation classification systems have been based primarily on potential vegetation or present vegetation. Each has its own degree of usefulness to the resource manager.

Potential Vegetation

Most potential vegetation classification schemes using perceived potential vegetation as a basis imply that there is only one potential vegetation community that may occur on any given physiognomic unit. Having a description of the perceived potential vegetation as a reference point is useful for making interpretations of present vegetation communities and provides a reference vegetation community for comparison purposes. However, it does not provide a resource manager with sufficient information on other vegetation communities capable of occupying the site, nor does it provide information on the range of natural resource products that might be produced on the site. There is also considerable difficulty and controversy involved in deciding what the climax vegetation was or what the potential vegetation community should be, particularly on those sites long influenced by human activities. Many times potential vegetation classification systems ignore the presence (or potential) of the exotic or introduced organisms that may or will influence the character of a site for centuries to come.

Present Vegetation

Classification schemes based on present vegetation are most often used in resource management because management strategies must be designed with the current situation as a starting point. Present vegetation classification systems often provide the resource manager with information about several optional vegetation communities available as a management objective, and, by having several tangible alternatives, the efficacy and efficiency of management is improved.

However, present vegetation classification systems, utilized without consideration of the potential vegetation, often result in misdirected and futile management. Management, aimed at producing a vegetation community not possible or within the site's inherent capability, has been attempted time and time again. Numerous land treatment projects have been undertaken, only to flourish for a short time, and then fail. Resource managers have received the brunt of the criticism for these so-called failures, when in reality they did not have sufficient information available to determine the true potential(s) of the site.

Paper presented at the Symposium, "Land Classifications Based on Vegetation: Applications for Resource Management," Moscow, ID, November 17-19, 1987.

Kris Eshelman and Robert Wagner are Range Conservationist and Range Scientist, USDI, Bureau of Land Management, Denver, CO.; Glen Secrist is Range Conservationist, USDI, Bureau of Land Management, Washington, DC.

THE CURRENT SITUATION

Ecological Sites

The Bureau of Land Management (BLM) currently uses the Range Site Concept (Dyksterhuis 1949; Renner and Allred 1962) as adapted from the Soil Conservation Service's (SCS) National Range Handbook (USDA 1976; USDI 1984). The range site concept, as used by the SCS, is based primarily on the perceived historical climax vegetation of a site and is often implied in site descriptions to be the potential climax vegetation or potential natural vegetation for the same site. Site descriptions generally allow a restricted range of variation of associated species and little to no allowance is made for the presence of introduced or non-native species. In the last several years there has been increasing acceptance of incorporating introduced and non-native species into site descriptions. Therefore the Range Site Concept is in essence a classification system based on historical vegetation with occasional allowances made for potential vegetation.

The Ecological Site Concept as used by the BLM is similar to the range site concept but follows the ecological site terminology and concepts as discussed in the Society For Range Management's (SRM) Range Inventory Standardization Committee (RISC) Report (SRM 1983). BLM cooperates with the SCS in the inventory and mapping of the soil resource, as well as developing or modifying range site descriptions.

Successional Concepts -- Range Condition

Range Condition is currently used by the SCS to imply a successional state, whereas the BLM actually states the perceived successional status of a particular site. Both agencies use coefficients of community similarity to determine the range condition of a site. Table 1 illustrates the ranges of similarity and the terms used by SCS and BLM for reporting range condition. Of particular interest is the assumption by each agency that their terms accurately express range condition. The SCS terms assert that the more dissimilar a site is from the perceived Climax Community (excellent condition) the poorer the condition of the site. There is no consideration for the uses or potential uses of the site other than for excellent condition. Even though proponents of the range site concept have stated that the Climax Community is not invariably the primary management objective (Dyksterhuis 1949; Shiflet 1973), many range management professionals and certainly the American public feel that anything less than Excellent or Good is unacceptable.

Table 1--Comparison of terms used for reporting range condition.

Percent Similarity	SCS Terms	BLM Terms
76%- 100%	Excellent	PNC
51 - 75	Good	Late Seral
26 - 50	Fair	Mid Seral
0 - 25	Poor	Early Seral

The BLM uses terms indicative of seral stage as described in the RISC report (SRM 1983). The presumption here is that a community dissimilar to the Potential Natural Community (PNC) is in an "earlier" seral stage. However, dissimilarity only indicates that the communities are dissimilar, not necessarily in an earlier seral stage. In spite of the use of the ecological terms for seral stage, many range management professionals and the American public again feel that anything less than PNC or late seral is unacceptable.

Since both agencies use the same technique to arrive at range condition ratings, it is assumed by many people that the terms are equivalent. "Early seral" is therefore assumed to be equivalent to "poor," "Mid seral" equal to "fair," and so on. They are not always equal.

The range condition problem for all agencies is similar. In the age of multiple-use management, should we report range condition as "poor" if our primary objective is to provide a reatively early seral habitat, dominated by forbs, for spring pronghorn range? Is reporting seral stage without reference to resource values really providing meaningful information at the national level? Is not seral stage more meaningful at a local level?

What is the condition of a mosaic of late seral sagebrush intermingled with early to mid seral forbs and grasses often considered to be prime sage grouse habitat? Do the terms currently used to report range condition accurately portray the management condition of the western rangelands?

Successional Concepts -- Philosophical

The range management profession developed its grass roots by adopting many of the concepts used by the livestock industry. The perception of what was good condition range obviously correlated to whether or not a cow, horse, sheep, or goat could find a full belly, produce healthy offspring, or find a place to hide from the extreme climate of the West. Range condition was synonymous with Forage Condition. To this day the life forms associated with "good range condition" are perennial grasses, tasty forbs, palatable shrubs, and desireable California annual grasses. It seems that the perceived climax communities on rangelands are usually described as having a dominance of these life forms. We have seemingly placed forage dominated communities at the acme of succession, relegating woody communities and thus woody species to the bottom of the sucessional pyramid or cone. Foresters on the other hand view the successional cone as always having trees at the pinnacle.

Natural succession is constantly moving many rangelands toward domination by woody vegetation. Sagebrush, pinyon, juniper, etc. are the potential cover types for millions of acres in the West. Many potential natural communities will be, as were the historical climax communities, dominated by woody vegetation. Why is it that following treatment to reduce sagebrush, we find sagebrush very quickly reestablishing and moving toward site dominance even in the absence of grazing?

What is the reason for calling woody communities lower seral? Are organisms that live 100-300 years truly more indicative of earlier seral stages than are herbaceous plants whose life span is 2-10 years? Shouldn't PNC or Climax be described as the community that develops through succession in the absence of disturbance? Catastrophic disturbance by fire, for example, has and will continue to create and maintain lower seral communities dominated by grasses and forbs.

There has been considerable interest in a disturbance theory of secondary succession. Little work has been done on rangelands, but it is our opinion that recognizing disturbance as a succession-inducing mechanism aids in explaining why wildland ecosystems function as they do. For discussion purposes, disturbance includes fire, chaining, grazing, animal-induced perturbations (badgers, ants, etc.), and seeding. Disturbance also includes weather and climatological events such as hail, intense rain, flooding, severe drought, extreme wind, and extreme temperatures. Recognizing that disturbance is selective, often influencing only a few species, aids in explaining why some species suddenly increase or decrease in an ecosystem. Considering a disturbed ecosystem or site as a lower successional community relative to an undisturbed ecosystem or site would be a major step toward understanding ecosystem dynamics.

Although disturbance implies negative impact, disorder, or chaos, disturbance can be a positive factor for some species and negative for others. Above-normal precipitation as a disturbance may promote the increase of species A, the increased dominance of species A in turn disturbs the habitat of species B, thus causing a decrease in species B.

A disturbance theory can also account for why early successional species often occur with late seral species on the same site. The late seral species have not been disturbed, but disturbances to the soil surface have provided annual weedy species with a receptive habitat. When estimating ecological status how many times do resource managers find late seral sagebrush coexisting with early seral cheatgrass and their coefficient of community similarity calculations end up averaging late seral species and early seral species into a mid seral stage community?

WHAT THE FUTURE MAY BRING

Ecological Site Concept

The ecological (range) site concept is and will remain a useful tool for assessing the productive capability of ecosystems. Soil mapping and soil survey are and will continue to offer insights into the most efficient uses, potentials, and limitations of the public lands. The techniques to acquire the data used for describing ecological sites will evolve, moving from a productivity basis to a basis that includes other attributes such as cover and density.

It is anticipated that our perceptions of what constitutes the climax community or potential vegetation community will move toward recognizing that many exotic species are permanently established and will remain on our "native" rangelands. We will recognize that nature is in the process of adding species to the earth's surface as well as removing the species we call Threatened and Endangered.

The perception of historical climax for a site being one and only one pristine "pre-European man" vegetation community should change to a perception recognizing that the first European (or Indian) probably saw a number of pristine seral communities in various stages of succession (Burkhardt 1987). It is difficult to imagine that succession did not occur until Europeans arrived.

Seral Communities

The seral community type concept as described by Leonard and others (1987) offers the potential for arriving at a classification system describing both potential vegetation and present vegetation. The seral community type concept allows descriptions of the perceived historical climax, and the perceived potential natural community, as well as the located, sampled, and documented plant communities known to occupy a given soil/landscape unit.

Using any and all sources, the concept basically aggregates data about vegetation communities known to occur on an ecological site. Data sets are segregated based on a common attribute such as production or canopy cover. Samples are then sorted into unique seral communities based on the three or more most dominant species. Table 2 illustrates actual data from one ecological site in California and the resulting community types as sorted to a species composition (air dry weight) of greater than or equal to 5 percent (USDI, BLM 1987.)

Working site-by-site and seral community-by-seral community, the data are analyzed by resource specialists familiar with the area. Data exceeding normal expected values, sampled in ecotones, or sampled by combining two ecological sites, are removed from the database. The similarity indices of each sample are assessed as to their pertinence in describing a particular seral stage. If necessary the seral stage name is changed to one more accurately describing the seral community's seral position, assuming that the review team can agree on successional concepts.

Table 2--Seral community types-Stony Slope South Ecological Site

Potential natural community	Late seral	Mid seral	Early seral
EPVI 50 %	AGSP 40 %	AGSP 32 %	BRTE 54 %
AGSP 28 %	ARTRV 24 %	CHNA2 19 %	ERIOG 22 %
AMSIN 6 %	LUPIN 10 %	TECA2 17 %	SIHY 12 %
ARTRV 6 %	STTH2 10 %	ASTRA 15 %	ARTRV 10 %
AGSP 29 %	AGSP 64 %	HODI 50 %	BRTE 48 %
PHLOX 17 %	ERIOG 12 %	RIBES 25 %	ERIOG 39 %
AAFF 13 %	PHLOX 12 %	ELCI2 11 %	SIHY 7 %
PHAC 13 %		ARTRV 6 %	
ARTRV 9 %			
	AGSP 35 %	PUTR2 26 %	TAAS 46 %
	EPVI 33 %	ARTRV 24 %	BRTE 19 %
	ARTRV 19 %	AGSP 22 %	EPVI 15 %
	BRTE 5 %	CHNA2 13 %	AMSIN 7 %
		AGSP 53 %	
		BRTE 26 %	

The final step in the analysis process is to address the causal agents that may have been involved in creating each seral community type. For example, if monitoring, inventory, or professional observations have detected that a fall prescribed fire causes seral community A to consistently become a seral community B, fall prescribed fire is listed as a causal agent between seral community A and seral community B. The important point with this last step is that documentation of causal agents should eventually lead to improved management. Many cause and effect relationships are discussed in the literature, but few resource managers or livestock producers have the time to search the literature for the cause and effect relationships pertinent to the ecological sites in their area. In addition, the documentation of cause and effect relationships in local ecological site descriptions will allow resource managers and livestock producers a means to document their knowledge and experiences without having to endure the often lengthy and laborious process of publishing their findings.

Rangeland Condition Reporting

As previously discussed, range condition has been historically biased toward domestic livestock; many people perceive potential (climax) vegetation as containing a major component of livestock forage species. Only within the last decade have we begun to recognize that nonforage species are an important component of an ecosystem. The passage of the Federal Land Policy and Management Act of 1976 sent a formal declaration to the BLM that the Public Lands should be managed using the principles of multiple use and sustained yield.

The Public Rangelands Improvement Act of 1978 (PRIA) defined range condition (for Federal land management agencies) in Section 3(d) as:

> (d) The term "range condition" means the quality of the land reflected in its ability in specific vegetative areas to support various levels of productivity in accordance with range management objectives and the land use planning process, and relates to soil quality, forage values (whether seasonal or year round), wildlife habitat, watershed and plant communities, the present state of vegetation of a range site in relation to the potential plant community for that site, and the relative degree to which the kinds, proportions, and amounts of vegetation in a plant community resemble that of the desired community for that site. (Emphasis added)

Congress clearly stated that it desired a multiple-use-based report that considered Land-Use Plan and Range Management Objectives. The BLM is currently investigating an alternative method for reporting how well the Public Lands are meeting the Land Use Plan's resource objectives. The BLM is considering reporting "Ecological Status" and "Management Status" in lieu of the old term Range Condition. Ecological Status would be reported using the criteria discussed previously, whereas Management Status would be a new term but not really a new concept to the range community.

Using a key term taken from PRIA, Management Status would be based on how well a tract of land was producing vegetation in comparison to the "Desired Plant Community" or Desired Plant Communities for the same tract. Using an interdisciplinary team and public input, the desired plant community(s) for a tract of land would be selected from the seral community types documented and shown to be capable of occurring on the tract. In some cases the desired plant community might only be a description of that proportion (or ranges of proportions) of trees, shrubs, forbs, or grasses needed to meet the needs of the resources concerned.

Vegetation Management Status would be determined by using a coefficient of community similarity to compare present vegetation to that in the Desired Plant Community. Terms used to report management status could be very simple such as "Meeting the Vegetation Management Objectives" (greater than 75 percent similarity) and "Not Meeting the Vegetation Management Objectives" (less than 76 percent similarity) or could be more qualitative such as "Excellent," "Good," "Fair," and "Poor" using the same coefficient of community similarity criteria as shown in table 1. Use of the latter terms would allow comparison to historical range condition reports, but could cause confusion since the new system (which uses a combination of ecological status and resource value rating to arrive at a desired plant community) could not be directly compared to the old system (which was based primarily on forage condition).

Trend could be reported by determining whether the present community was moving "Toward the Desired Plant Community(s)," "Away From the Desired Plant Community(s)," or "Not Apparent." Other optional terms could be the terms "Toward the Vegetation Management Objectives," "Away from the Vegetation Management Objectives," or "Not Apparent."

A simple example may aid in understanding the principle. A management unit is predominantly loamy upland, characterized by as much as 50 percent sagebrush canopy with a moderate understory of perennial herbaceous vegetation. The same ecological site outside the management unit produces seral communities dominated by bitterbrush, sagebrush, or significant amounts of perennial grass. The major Land-Use Plan objectives are to provide winter and spring habitat for a resident deer herd, provide year-round forage for livestock, provide habitat for sage grouse, and to prevent accelerated erosion.

Through interdisciplinary review and cooperation, one-third of the unit is meeting the LUP objectives by producing a good mixture of sagebrush and herbaceous vegetation. One-third of the area is targeted for prescribed burning to enhance grass production, whereas the remaining one-third requires special grazing practices to enhance bitterbrush production. Under the old range condition concept the entire management unit would probably have been reported to be in fair condition. But, under the proposed concept one-third would be reported as meeting the LUP objectives and two-thirds would be reported as not meeting the LUP objectives.

Public Lands that are of low potential (creosote bush and shadscale) would be reported as "Meeting the Vegetation Management Objectives" if the LUP indicated that it was technologically not feasible or uneconomical to convert low producing sites into short-term productive ones. Under the BLM's Selective Management approach most of the acreage occurring within the "Maintain" or "Custodial" categories could be reported as "Meeting the Vegetation Management Objectives."

A CALL FOR ANALYSIS AND CHANGE

Present and Potential Vegetation

A classification system, to be usable to the resource manager, must be able to accommodate historical, present, and potential vegetation concepts. The seral community type concept, as discussed in this paper, offers one possibility as a classification system incorporating both present and potential (as well as historical) vegetation concepts. Use of such a system would allow all agencies, disciplines, and resource users access to the same information, and still allow each to apply their own concepts to the data.

Cover and Production

For obvious reasons, different classification systems depend or are based on different attributes of vegetation. Some use cover, some use productivity. In the computer age why not do both? Even though cover and production cannot be directly correlated, they both provide useful information. Canopy (crown) cover appears to be the most universal attribute since sampling can be performed fairly easily on almost all ecosystems. Cover also relates to a considerable number of multiple-resource-related data needs, including wildlife habitat cover, watershed management, and fire management. Productivity is valuable for establishing forage value and suitability, and for making estimates of site potential, but is difficult to sample uniformly over all ecosystems.

National Standards and Review Committee

The title of this paper could have been "Deregulation of the Classification Industry". To some, deregulation means freedom to do what one desires, the ultimate to those in scientific pursuits. To others deregulation means chaos, an inability to achieve consistency, and difficulty in comparing information. The economics of deregulation are difficult to assess. On one hand deregulation produces cost reductions, on the other we waste time reinventing the abacus. Classification must be standardized. It is amazing that the most scientifically advanced Nation on this planet has no means to make a common comparison among all ecosystems and among all agencies, State and Federal.

A national committee should be established to develop a National Ecological Classification System. This national committee could be patterned after the National Cooperative Soil Survey, a now effective and functional group. A vegetation-oriented group (including, but not limited to, range, forest, and wildlife ecologists) would be more complex considering the differences of opinions on ecology, succession, terminology, and methods; but should the group prove to be successful, resource management would step into a new era, driven by the availability of new common knowledge and, by cooperation.

Range Condition

Range Condition has been a controversial subject for nearly a century. In the early years of range management, range condition was forage condition; cattlemen had (have) different ideas on range condition than did (do) sheepmen. Today the perspective of range condition has expanded to wildlife habitat, watershed protection, wilderness values, recreation, etc. It is time to change the way we determine and report resource conditions. We have presented an alternative that may provide a wide-spectrum classification system, an improved management tool, and possibly an improved condition reporting system that will substantiate improved multiple-use resource conditions on the Public Lands.

REFERENCES

Allen, Barbara. 1987. Ecological type classification for California: the Forest Service approach. Gen. Tech.Rep. PSW-98. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Bailey, Robert G., Compiler. 1978. Description of the ecoregions of the United States. Misc. Pub. 1391. Washington DC: U.S. Department of Agriculture, Forest Service. 77 p.

Burkhardt, J. Wayne. 1987. [Personal Communication] October 29. Reno, NV. University of Nevada-Reno.

Dyksterhuis, E. J. 1949. Condition and management of rangeland based on quantitative ecology. Journal of Range Management. 2:104-115.

Leonard, S. G.; Eshelman, K. R.; Miles, R. L.; Wagner, R. E. 1986. A method to display seral community types for multiple use management. Unpublished Report. U.S. Department of the Interior, Bureau of Land Management. 12 p.

Paysen, Timothy E.; Derby, Jeanine A.; Black, Hugh Jr.; Bleich, Vernon C.; Mincks, John W. 1980. A vegetation classification system applied to Southern California. Gen. Tech. Rep. PSW-45. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 33 p.

Renner, F. G.; Allred, B. W. 1962. Classifying rangeland for conservation planning. Agric. Handb. 235. Washington DC: U.S. Department of Agriculture, Soil Conservation Service. 48 p.

Shiflet, Thomas N. 1973. Range sites and soils in the United States. In: Arid shrublands--proceedings of the Third Workshop of the United States/Australia Rangelands Panel. 1973 March 26-April 5. Tucson, AZ: 26-33.

Society For Range Management. 1983. Guidelines and terminology for range inventories and monitoring. Report of the Range Inventory Standardization Committee. Denver, CO. 36 p.

USDA, Soil Conservation Service. 1976. National Range Handbook, NHR-3. Washington, DC.

USDI, Bureau of Land Management. 1984. Ecological Site Inventory. Manual Handbook 4410: H-4410-1. Washington, DC.

USDI, Bureau of Land Management. 1987. Unpublished Draft Report. Susanville field test of seral community types, desired plant community, and vegetation management status. Washington, DC.

ON FURTHERING THE USE OF HABITAT CLASSIFICATIONS IN WILDLIFE HABITAT MANAGEMENT IN THE NORTHWESTERN UNITED STATES

James M. Peek

ABSTRACT: Vegetation classifications are used extensively in wildlife habitat management activities in the northwestern United States, but are likely to be used more as habitat management becomes more intensive. Currently, most attention is given to stand structure and plant succession, without extensive consideration of site potential. Currently, the need to monitor the results of habitat management recommendations is a high priority, but eventually predictions of vegetative and animal response, geared to site potential to produce certain kinds of vegetation, should receive more effort. We have tools to predict plant succession, coordinate vegetative manipulations over large areas, and an understanding of habitat use patterns of elk which could be used to initiate this kind of planning effort.

INTRODUCTION

In order to understand where wildlife habitat managers and researchers might advance in the area of keying wildlife to better habitat descriptions, we might start with a bit of history. First, it might be worth recognizing that even prior to Leopold wildlife conservationists were aware of the need to adequately describe habitats wildlife used. Herbert Stoddard's efforts to enhance bobwhite populations in the southeast involved understanding pathways in plant succession and efforts to manipulate succession with fire. Some of the early impetus to identify what the undisturbed vegetative component consisted of came from wildlife biologists. Wallace Grange was among the earliest to identify and understand how trends toward climax in the Wisconsin forests adversely affected deer and grouse populations.

However, from the practical management side of wildlife conservation in the western states and elsewhere, two major efforts have occurred over the past 40 years that are based on understanding plant succession and climax. The effort still in practice is the seral shrub burning program, instituted in the 1960's, to retain and enhance big game winter range. The landmark monograph on succession in the cedar-hemlock zone of northern Idaho by Mueggler (1965) described the vegetation, while the work of Leege (1969) and his colleagues describes results of the burning programs. This work eventually led to expansions of the program to summer-fall burning on critical winter-spring range complexes, as distinguished from just the so-called critical winter range. Prescriptions and descriptions of fire's effect on various forested communities have emanated from this early work, in ponderosa pine (Merrill and others 1982), bitterbrush (Bunting and others 1985), and more mesic habitat types (Zimmerman and Neuenschwander 1984; Lyon 1971, 1976). The prescriptions that allow wildfires to burn in wilderness were supported by wildlife biologists, who saw benefits to wildlife, as well as the restoration of a natural dynamic process.

The other major area dealt with condition-trend evaluations of winter forage on rangelands. Big game winter range management has often been based on the assumption that productive shrub and grasslands at near climax condition were the goal, and experience with the wildlife management areas that provided winter range has shown this goal to be achievable. The descriptions of habitat types such as those of Daubenmire (1970), Mueggler and Stewart (1980), and Hironaka and others (1983) all provide information on what the vegetative potential is for different sites. This activity has been severely curtailed because of methodological problems, no apparent correlation between population trend and vegetative condition, and changes in priorities.

While these activities have been institutionalized to varying degrees by the agencies dealing with wildlife habitats, perhaps the area where most interest has been directed recently is in the management of forested habitats used by big game as summer and fall range. There were no real incentives to worry over this issue until logging became more pervasive in the early 1970's. The elk-logging guidelines were developed to help coordinate forestry and wildlife habitat management (Leege 1984). These guides, when initially considered, demonstrated the lack of sufficiently detailed information on habitat use patterns of the various wildlife species.

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James M. Peek is Professor, Wildlife Resources, University of Idaho, Moscow.

This subsequently lead to a wide array of habitat use studies, especially of elk and a few of the endangered or rarer species, that helped to bridge a fundamental communication gap between resource managers.

Early descriptions of use patterns which used highly subjective terms like open versus dense forest were not adequate. Now, with the advent of telemetry and the habitat type classifications, a location of an animal can be pinned to a rather specific site, the floristics, both current and potential of which, can be described. So the habitat type classifications have served as a major vehicle by which wildlifers and foresters have been able to more effectively communicate with each other. I believe this in itself is one of the most significant benefits of these plant community descriptions.

There is still a major problem dealing with terminology, however. Habitat type, as a concept dealing in plant community classification, relates to site potential and is a very specific term. However many wildlifers use habitat type in a more generic context to mean currently existing vegetation. This dichotomy persists and one needs to be certain all involved understand which definition is being used. However, wildlife biologists should recognize the more specific definition of habitat type and refer to the current vegetative complex as the cover type.

Site potential to support a given vegetative complex is important, but the wildlife biologist most often focuses on plant succession and vegetative structure. For instance, redstem ceanothus, the major browse species in north Idaho, exists as a major seral species following fires in a variety of habitat types from those in the Douglas-fir series through the grand fir series into the cedar series. Management to retain redstem should eventually be predicted according to the habitat type involved, but currently an inspection of plant condition is often sufficient to determine management. Plant succession is being manipulated and the focus is on maintenance of a specific seral stage without much concern for site potential.

However, prescribed burning programs on big game habitat are now being expanded to include areas away from the lowest and driest southerly exposed slopes. Vegetative response to burning will differ on various exposures, moisture regimes, and habitat types. As these programs become more prevalent, a knowledge of site potential and plant succession following burning on different areas will be needed.

At the opposite end of the successional sequence, old-growth-dependent species require specific kinds of stand structure, such as large snags for nesting. While even here succession is ultimately involved, retention of old-growth habitat with certain characteristics is the usual management approach. However the need to predict where old-growth with desired characteristics occurs and will occur in the future will inevitably involve determinations of site potential.

Investigations into plant succession and into management for certain stand structures are important in wildlife habitat management. Efforts to identify seral stages that are preferred habitats must be based on descriptions of vegetative seres and associated structural characteristics, and related to site potential.

Currently, management considering the habitat type exists in certain instances. Critical habitat for mountain caribou on the southern limits of their range is identified as the upper limits of hemlock/pachistima in early winter and the subalpine fir/beargrass and subalpine fir/menziessia habitat types in late winter (Scott and Servheen 1984). Moose prefer to winter in the Pacific yew phase of the grand fir/ginger habitat type in central Idaho (Pierce and Peek 1986). While the native big game species exhibit broad habitat use patterns that include many habitat types, even white-tailed deer habitat use patterns can be predicted at the habitat type level (Owens 1981). Dense seral stages of grand fir/pachistima and cedar/pachistima habitat types were preferred deer habitat on the Palouse Range. White-tailed deer preferred to winter in unburned Douglas-fir/ninebark in the upper Selway River, Idaho (Keay and Peek 1980). Jageman (1984) was able to relate habitat management for white-tailed deer to habitat type, stand type, site index, and successional patterns within habitat types.

The habitat type was one significant predictor of elk habitat preferences on the Gospel-Hump area in central Idaho by Scott and others (unpublished manuscript). Ponderosa pine/bluebunch wheatgrass was highly preferred elk winter habitat on the Salmon River drainage in this area. However, Irwin and Peek (1983) reported elk using a variety of successional stages in several habitat types at different times of the year in north Idaho, which illustrates variability of use patterns and potential predictors of habitat use for this species between different areas. Many of the nongame birds have habitat requirements most appropriately keyed to stand structure, with assessment of site potential being of less utility.

Habitat use patterns of mule deer on rangelands can also be readily related to site potential. In north-central Washington, Carson and Peek (1986) reported that riparian communities were preferred habitats, with the most xeric sagebrush stands, especially those in poor condition being least preferred. Three-tip sagebrush communities were favored winter deer habitats in east-central Idaho (Moir 1976; Wittinger 1978; Kvale 1981; Yeo 1981). Recently burned Douglas-fir/ninebark and ponderosa pine/bluebunch wheatgrass habitat types were preferred winter mule deer habitat in the upper Selway River drainage, Idaho (Keay and Peek 1980).

The bluebunch wheatgrass/Sandberg bluegrass habitat type is common across montane rangelands in Idaho, Oregon, and Washington. Bodurtha (1987) reported that stands in high condition, and mid-seral stages with high vegetative diversity were preferred mule deer habitat. This initial effort to relate wildlife habitat use to a grazing-induced sere in a major habitat type should be extended, as a means to further integrate range management activities with wildlife habitat management.

Site potential turned out to be extremely important in determining management for ponderosa pine stands with bitterbrush understories that occur in the Salmon River canyonlands in central Idaho. Many of these stands are in the Douglas-fir/snowberry habitat type, and will eventually succeed to communities devoid of bitterbrush (Peek and others 1978). One appropriate prescription includes selective cutting and site scarification to foster bitterbrush seedling establishment. Identification of the habitat type in which these important stands occurred was the impetus for considering appropriate alternatives to manage the stands as valuable winter range for big game.

I consider the habitat management guidelines that are available for the various wildlife species to be well-thought-out initial efforts at attempting to integrate forestry, rangeland, and wildlife habitat management. However, they are considered general guides intended for use over relatively large areas that must be tailored for specific conditions. As these recommendations become more widely applied, the need to monitor wildlife and vegetative responses becomes ever more critical. While this monitoring problem is most critical, the need to develop more quantitative approaches to integration of wildlife habitat management and forestry practices is also apparent. Tools are now available to do this. The stand prognosis model developed by Stage (1973) has been extended to include understory and shrub responses by Moeur (1985). Using these predictive models, and mapping systems which determine spacing, size and interspersion of stands through time, we can describe models of vegetative change for specified population entities, such as one elk herd. The available habitat use data for this species could be readily incorporated into such analyses for many areas in this region. Access management plans can readily be integrated into this procedure. Eventually, we will need to transfer more of our efforts toward predictions rather than just on mitigating currently planned activities using the available guides. There is now sufficient knowledge concerning plant succession, stand development, and habitat use patterns to do this at least for elk. As we get into such efforts, the habitat type once again will serve as the primary basis for communication and cooperation.

REFERENCES

Bodurtha, T. S. 1987. Habitats, habitat use, food habits, and population characteristics of mule deer inhabiting a mountain foothill winter range in northeastern Oregon. Moscow, ID: University of Idaho 306 p. Thesis.

Bunting, S. C.; Neuenschwander, L. F.; Gruell, G. E. 1985. Fire ecology of antelope bitterbrush in the northern Rocky Mountains. In: Lotan, J. E.; Brown, J. K., comp. Fire's effects on wildlife habitat, Symposium Proceedings. Gen. Tech. Rep. INT-186. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 48-57.

Carson, R. G.; Peek, J. M. 1987. Mule deer habitat selection patterns in northcentral Washington. Journal of Wildlife Management. 51: 46-51.

Daubenmire, R. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA. Washington Agricultural Experiment Station. 131 p.

Hironaka, M.; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bulletin 35. Moscow, ID: University of Idaho Forest, Wildlife, and Range Experiment Station. 44 p.

Irwin, L. L.; Peek, J. M. 1983. Elk habitat use relative to forest succession in Idaho: Journal of Wildlife Management. 47: 664-672.

Jageman, H. 1984. White-tailed deer habitat management guidelines. Bulletin 37. Moscow, ID: University of Idaho Forest, Wildlife, and Range Experiment Station. 14 p.

Keay, J. A.; Peek, J. M. 1980. Relationship between fires and winter habitat of deer in Idaho. Journal of Wildlife Management. 44: 372-380.

Kvale, C. T. 1981. Mule deer, elk, and cattle relationships on the Herd Creek rest-rotation grazing system, East Fork of the Salmon River, Idaho. Moscow, ID: University of Idaho. 202 p. Thesis.

Leege, T. A. 1969. Burning seral brush ranges for big game in northern Idaho. Transactions of the North American Wildlife Conference. 34: 429-435.

Leege, T. A. 1984. Guidelines for evaluating and managing summer elk habitat in northern Idaho. Wildlife Bulletin 11. Boise, ID: Idaho Department of Fish and Game. 37 p.

Lyon, L. J. 1971. Vegetal development following prescribed burning of Douglas-fir in south-central Idaho. Res. Pap. INT-105. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 30 p.

Lyon, L. J. 1976. Vegetal development on the Sleeping Child Burn in western Montana, 1961-1973. Res. Pap. INT-184. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Merrill, E. H.; Mayland, H. F.; Peek, J. M. 1982. Shrub responses after fire in an Idaho ponderosa pine community. Journal of Wildlife Management. 46: 496-502.

Moeur, M. 1985. COVER: a user's guide to the canopy and shrubs extension of the stand prognosis model. Gen. Tech. Rep. INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 49 p.

Moir, B. C. 1976. Movement and range use patterns of mule deer in the Pahsimeroi Valley, Idaho. Moscow, ID: University of Idaho. 89 p. Thesis.

Mueggler, W. F. 1965. Ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. Ecological Monograph. 35: 164-185.

Mueggler, W. F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Owens, T. E. 1981. Movement patterns and determinants of habitat use of white-tailed deer in northern Idaho. Moscow, ID: University of Idaho. 48 p. Thesis.

Peek, J. M.; Johnson, F. D.; Pence, N. N. 1988. Successional trends in a ponderosa pine/bitterbrush community related to grazing by livestock, wildlife, and to fire. Journal of Range Management. 25: 178-189.

Pierce, D. J.; Peek, J. M. 1984. Moose habitat use and selection patterns in north-central Idaho. Journal of Wildlife Management. 48: 1335-1343.

Scott, M.; Nelson, L. J.; Peek, J. M. 1987. Gospel Hump Elk studies. Unpublished manuscript on file at: Department of Fish and Wildlife Resources, University of Idaho, Moscow, ID. 30 p.

Scott, M; Servheen, G. 1984. Caribou ecology. Job Progress Rep. Project No. W-160-R-11. Boise, ID: Idaho Department of Fish and Game 78 p.

Stage, A. R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Wittinger, W. T. 1978. Habitats, food habits, and range use of mule deer, elk, and cattle on the Herd Creek rest-rotation grazing system, East Fork of the Salmon River, Idaho. Moscow, ID: University of Idaho. 125 p. Thesis.

Yeo, J. J. 1981. The effects of rest-rotation grazing on mule deer and elk populations inhabiting the Herd Creek allotment, East Fork Salmon River, Idaho. Moscow, ID: University of Idaho. 119 p. Thesis.

Zimmerman, G. T.; Neuenschwander, L. F. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/ninebark habitat type. Journal of Range Management. 37: 104-111.

RESEARCH AND INFORMATION NEEDS FOR LAND CLASSIFICATIONS BASED ON VEGETATION

Robert D. Pfister

ABSTRACT: Research and information needs are summarized from two sources: symposium speakers and a poll of symposium participants. Meeting these needs will require coordination and cooperation from research, management, and educational organizations. Numerous opportunities exist to advance the science of applying ecological information to natural resource questions, but these opportunities will not be realized without individual and corporate dedication.

INTRODUCTION

Where do we go from here? What are the next logical steps for application of ecological land classification to natural resource management? This involves documenting research and information needs, but it is not that simple because *research needs* implies research responsibility and *information needs* implies what managers need from research and educational organizations.

We all know that managers and management agencies also have a strong hand in developing and disseminating information. The question is not simply, *what* is needed? The real question is, *who* will provide it? We have not reached where we are today by a simplistic approach and we will not progress very fast unless we look at the future with a more cooperative, coordinated, and holistic perspective.

This paper will list research and information needs, but before we do, let us address the framework and perspective necessary to move forward in meeting those needs. Everyone in this room has a vested interest, and many have a professional responsibliity, or at least an opportunity, to assist in meeting these needs.

APPLICATION CONCEPTS

Earlier, I discussed a number of points under the heading of Application Concepts (Pfister this symposium). The main points are repeated here, because all are essential in moving forward to continue to meet research and information needs:

Decision About the Kind of System--This process has been completed by some agencies for some ecosystems. Formal ecology programs have been developed by most USDA Forest Service Regions to complete the classifications, develop management applications, conduct training, and do whatever is necessary to provide for the needs that research and educational organizations have not met (for example, Allen 1985). These programs have a large influence on all natural resource research and management within their geographic area.

However, deliberation is still in progress for rangeland ecosystems and riparian ecosystems in most areas and for all ecosystems within some agencies. Land management and research organizations need to decide what kinds of ecological classification systems are most appropriate (coordination of research and management on this decision is vital).

Planning, Finances, and Personnel--Once basic decisions are made, the plan specifies the tasks, priorities, timetables, finances necessary, and responsibilities. This is the opportune time to document coordination and shared responsibilities of researchers, managers, and educators. Once the plan is approved, qualified personnnel must be obtained to carry out the program.

Developing the Taxonomy--Whether termed *research* or *administrative study*, quality control (from data collection through analysis, interpretation, and publication) is critical and requires scientists with solid ecological credentials. Methodology is quite well documented, but improved techniques should be continually sought. Shortcut approaches have been suggested, but many are poorly conceived and fail when put to the application test.

Training the Users and Application Specialists--Training is crucial and includes understanding of concepts, indicator species recognition, proper use of keys, mapping techniques, and proper interpretation of available management implications. Research and management specialists who are developing new applications need the training just as much as other users.

Developing Applications for Natural Resource Management--Applications require development of the relationships between the ecological classification (and the ecological knowledge contained therein) and appropriate natural resource concerns. This can be done in several ways:

a. By ecologists, from supplementary data and observations.

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Robert D. Pfister is Research Professor, School of Forestry, University of Montana, Missoula, MT.

b. By research specialists who stratify their data, analyze, and report results in relation to habitat types.

c. By management specialists, summing up their own data, observations, and experience to develop their own local (usually informal) guidelines.

d. By teams of ecologists, resource scientists, and management specialists, pooling their combined knowledge and intuition for a synergistic, documented contribution to knowledge.

e. By symposia such as this one! Concepts for application (or linking of site classifications to resource management) have been evolving for some time and this symposium is the first formal effort to assess how far we have progressed. New ideas and concepts require time and understanding of their value to be accepted and implemented.

Each of the approaches has some problems. Many ecologists do not have a strong backgound in the natural resource areas where interpretations are needed. Many research specialists do not have enough ecological background to make full use of the classification. Management specialists may solve their current, local problems but there is no mechanism to capture the knowledge for use in other areas. Team efforts offer the most promise for solid, documented applications. However, team efforts require cooperation, coordination, commitment, and support of upperlevel management. If formal team efforts are not possible, it behooves professionals to find a way to work cooperatively with other professionals for specific areas of concern.

Symposia are an effective way to provide a documented update on status of knowledge--this symposium goes a critical next step by addressing the question--"Where do we go from here?"

HISTORICAL PERSPECTIVE

The historical perspective provides understanding of how we got to where we are today--and some lessons for the future. The association concept was established in the late 1800's, discussed in the early 1900's, and first developed as a practical site classification tool in the U.S. with the introduction of the concept of "habitat type" by Daubenmire (1952). During the 1960's, some specialists began applying the classification to natural resource questions, graduate students were developing classifications for new areas, and a few professors were training undergraduates in the concepts and practical aspects of using the classifications.

The 1970's were the heyday of developing classifications for new areas and the beginning of applications. Land use planning began to incorporate ecological concepts. The USDA Forest Service, both Research and the National Forest System, provided financing and personnel to expand classification systems to areas not previously studied. Professors provided guidance to a large number of graduate students developing classifications for new areas.

Many researchers began to use the classifications as a research tool for stratification and interpretation of results in a format that could be applied back to specific ecosystems. Formal training sessions were established to enable a wide range of natural resource professionals to apply available classifications and management implications to natural resource management questions. Some universities developed special courses designed to equip the graduate with the skills to apply ecological classification the first day on the job; and many employers required this educational background as a job prerequisite.

What has happened during the 1980's? What started as a research program has become almost entirely a development and application program. Research funding for ecological classification work has almost disappeared, both internally within research organizations and as grant funding for professors to support graduate student programs. Some justify this state of affairs by saying, "the research has been done." Others, closer to the subject, agree that the classifications (taxonomies) are the means to the end, not the end in itself, and that current managment applications are only the tip of the iceberg. We are at a turning point, or may have already passed that point, and the enthusiastic participation in this symposium illustrates both concern and promise.

Fortunately, those land management agencies with sufficient resources (such as the National Forest System) have accepted almost full responsibility for carrying on the classification and application responsibilities. In effect, they are now running true RD&A ecological programs with minimal research involvement and minimal opportunity for university research and education involvement. Coordination and cooperation are far less than optimum for a RD&A concept of such great potential.

ECOLOGICAL AND NATURAL RESOURCE SCIENCE

If we accept that science involves four basic steps--observation, description, classification, and abstraction--then, how far has the science of applying ecological concepts to natural resource management progressed? Classification is "completed" for some areas, although refinements would undoubtedly add precision. Choices, or perhaps a balance of effort, are needed between using resources for continual refinement versus getting on with the job of abstraction.

But, who is going to do the abstraction? If the science is expected to progress past step three, then scientists need to be presented with both the challenge and the opportunity to proceed with the process of abstraction.

One product of abstraction is simplification--which makes the job of classification more efficient for new areas and provides a better basis for effective education and training. Another product of abstraction is understanding of the basic ecological relationships and processes--which leads to better application of the information. A third product of abstraction could be improved linkage of ecological information to natural resource questions--which is the central thrust of this symposium.

Three major obstacles have been slowing down advancement of the science of applying ecological information to natural resource management. The frustrating aspect of these obstacles is that they are internal--as Pogo (comic strip) said, "We have met the enemy, and he is us!" Lee Iacocca (of Chrysler fame) labels this kind of problem as "identifying the *naysayers* within an organization and getting rid of them!" (Easier said than done in most organizations!) The three problems I refer to are:

Inadequate Research Support--Forest Service Research deserves major credit for developing, financing, and publishing much of the classification and application work during the past 20 years. The Forest Service definition of research is: a) development of new knowledge and b) new applications of existing knowledge through improved techniques and methods. Development of classifications for new areas fits the first definition in the minds of most ecologists who realize that each new area has unique species-site interactions to be discovered--development of new knowledge. The *naysayers* argue that this is really development work, since the basic concepts and methodology are established. Nevertheless, Forest Service Research does not have sufficient resources to complete classifications for all areas--other sources of research funding must be found.

University Negativism--It is disconcerting to hear of professors in Forestry Schools who will not allow prospective graduate students to develop a habitat type classification for a thesis (because it is not a new concept!) or where ecology professors are discouraged from working on habitat type classification and application. On the other hand, few of us would be here today without those professors and universities who encouraged continued research and development of the habitat type concept for new applications to natural resource management. Since this problem varies greatly among universities and professors, we have the freedom of choice to select those universities that have the capability and desire to help meet the research and information needs we document here.

Management Program Isolation--With inadequate research funding and incomplete university support, some management agencies have found it necessary to develop their own special programs to get the job done. The Ecology Program of the USDA Forest Service Pacific Northwest Region is the most familiar example. Most Forest Service Regions in the western United States have, or are developing, similar formal programs. However, if the science is going to be done by a management agency alone, then there is an obvious danger of just mechanically and routinely getting the task done. If scientists are hired to expand the system, what happens to their new ideas and concepts? Do they have the opportunity to document and present these for the advancement of science? Is the management agency really doing research, or can it all be called administrative study? Some administrators get nervous when these questions are asked. Fortunately, the Chief of the Forest Service sent a letter to Stations and Regions in the early 1970's. This letter basically stated that we shouldn't get hung up on technicalities--there was necessary work to be done and that Regions and Stations should cooperatively get on with it. Farsighted administrators have found ways to get the job done and contribute to advancement of the science.

Much of the progress to date has been achieved through informal research, development, and application programs. The RD&A concept works very effectively. It can resolve most of the obstacles mentioned above. It also can include education needs that have been discussed. If informal RD&A concepts are not being utilized, then formal programs may be necessary to get the jobs done.

RESEARCH AND INFORMATION NEEDS--SYMPOSIUM SPEAKERS

Many of the speakers in this symposium have discussed needs (directly or indirectly) in their presentations. Some of their major points are summarized in this section:

Wellner listed seven points in his paper under the major jobs ahead:

1. Completing gaps in classifications.
2. Correlating existing classifications.
3. Developing classifications for seral communities with pathways and management implications.
4. Refining classifications.
5. Mapping of habitat types.
6. Developing better productivity estimates of each habitat type.
7. Fitting classifications by habitat types into an overall land classification framework.

Bourgeron listed four major points:

1. Correlation of local classifications at a regional or continental scale.
2. Models of diversity patterns at different levels of ecological organization.
3. System for managing ecological information.
4. Guidelines on conserving and managing units of classification.

Johnson emphasized the obvious need for more training as revealed by a survey.

Roberts and Morgan, Keane, Steele, and other speakers have all emphasized the major lack of information available on successional communities, even when the habitat type classifications are completed. Techniques for studying succession have been explored and proposed, but working models and classifications for seral community types will require a major effort for each geographic area of concern.

Hann discussed several problems in application that can be solved by:

1. Increased training.
2. Increased emphasis on correlation with other environmental factors.

3. Development of an ecological data base system.
4. Predictions based on seral classification and modeling.
5. Area evaluation in addition to stand evaluation.

Neiman and Hironaka pointed out some of the benefits that could be obtained through better knowledge of the correlations between potential vegetation, soil, and site characteristics within a specific region.

Schlatterer discussed three major needs:

1. Refinement by other environmental factors to adequately identify a usable potential.
2. Identification of mechanisms and factors that contribute to the arrest of seral development for long periods, or to the development of new potentials.
3. Modifications to satisfy the needs of the user for short-term predictions in early succession that a manager can use to make rational decisions.

Tisdale stated several needs relative to shrub-steppe areas:

1. Extension of classification to new areas.
2. Refinement of existing schemes in light of increased knowledge.
3. The biggest challenge--develop a better understanding and a workable classification of ecosystems supporting seral vegetation.

Volland described the need for and a new process for development of forage rating guides that is integrated with vegetation and site classification concepts.

Klebenow recognized the formidable need of outlining plant composition for all the seral stages of each ecological site, and concluded that research was needed to get a full understanding of the relationship between the successional stages of an ecological site and the reaction of wildlife.

Stage emphasized the need for "conservative evolvement" of revised classifications to make application developments more efficient.

Lyon reminded us that we must remember to be careful in all our enthusiasm. Research has things like statistics, experimental design, and peer review that are necessary to help us maintain objectivity.

Leonard and Miles recognized the lack of a unifying force for vegetation classification and interpretation in the broader sense--and that this force must come from, and involve, the major users of vegetation classification systems.

Other speakers have provided emphasis to the above points. The list of needs is overwhelming and priorities must be established. Who sets the priorities?

RESEARCH AND INFORMATION NEEDS--SYMPOSIUM PARTICIPANTS

During the symposium, I invited participants to write down the two most important research and information needs from their perspective. A total of 221 suggestions (which are summarized in Table 1) were received from 108 participants. Participants were asked to identify themselves as "researcher" or "user." Some found it difficult to identify cleanly with those two categories.

To summarize results, I included all ecologists actively developing classifications in the "research" category and all other kinds of staff specialists in the "user" category. There were still 15 that did not fit or did not identify themselves by category, which are identified as "unspecified."

The needs were listed by categories relative to previous discussions. Research and development needs are pooled, so that we do not point fingers at responsible organizations (the responsibility must be shared). The first group relates to vegetation (and site) classification--the foundation. The second group relates to management applications--the relationships that can be developed once a standard taxonomy is available. The third group is simply labeled as application, which lists some good suggestions relative to some possible direct uses of the classifications in land management. The fourth category, education, is a crucial part of furthering regular application by managers (and other research disciplines). The fifth category, administration, includes those comments from participants who recognized that the best ideas may never come to fruition without commitment from the top.

All needs are listed. Similar responses were paraphrased as recurring themes. Those needs with the highest scores provide a strong indication of where this audience thinks we should be going. Unique ideas were also listed. (Unique ideas may be "far out" or "new perspectives" or "locally important" --readers may make their own judgments.)

DISCUSSION

The three major items that must be addressed are succession, applications for resource management, and training. There are alternatives to tackle each of these needs.

Succession--If you look at the job of doing succession work with a complete sampling approach, it appears to be 10 times the task of the original habitat type classification work. Who is going to finance that size of a job? One participant suggested that the size of the problem could be partially solved by having management agencies help develop the data base. Is succession an area for research to look at methods of tackling this problem more efficiently? We have had some other good suggestions during the symposium. The next major scientific breakthough may well be an efficient way to handle the numerous questions about successional relationships.

Table 1--Summary of research and information needs from 108 participants (R=Researchers, U=Users, N=Not specified or other)

Research or information need	**(R/U/UN)**
A. RESEARCH AND DEVELOPMENT--VEGETATION CLASSIFICATION	
1. Develop successional pathway models and classification of seral communities (including treatments)	**(31/13/1)**
2. Need to coordinate, unify, or standardize concepts and approaches of classification to meet needs of users	**(12/10/3)**
3. Develop habitat type taxonomies for all areas not adequately covered	**(10/3/0)**
4. Determine relationship between vegetation classification topography and soils (to improve site specificity)	**(5/6/1)**
5. Develop multifactor (ecosystem) approach to classification that integrates vegetation, soils, landform, wildlife, and all resource needs	**(4/2/3)**
6. Develop regional correlations of classifications (including assoc.and range sites)	**(4/3/0)**
7. Develop analytical procedures for portrayal of successional stages and habitat types within a large area of analysis (landscape ecology)	**(0/1/1)**
8. Develop more concise objectives for classifications in order to test the validity (utility) of these classifications	**(1/0/0)**
9. Correlate ecological and genetic parameters	**(1/0/0)**
10. Develop comprehensive models of vegetation behavior within types	**(1/0/0)**
11. Resolve the question of whether an individual species is a better definition of a "responding unit" than a "community class" and proceed accordingly	**(0/1/0)**
12. Take a hard look at the assumption that Daubenmire's classification concepts/methods apply wholesale to forests or nonforest vegetation elsewhere	**(0/1/0)**
Subtotal-Part A	**(70/39/9)**
B. RESEARCH AND DEVELOPMENT--MANAGEMENT APPLICATIONS	
1. Develop (synthesize, summarize, test, and refine) management interpretations and natural resource applications of habitat types (and successional stages)	**(12/8/5)**
2. Develop methodology to improve relationships of habitat types to productivity	**(4/3/0)**
3. Determine relations between habitat types/successional stages and insects/diseases	**(2/0/0)**
4. Provide an understanding of long-term effects of forest use	**(1/0/0)**
5. Ecotone identification and mapping techniques	**(0/0/1)**
6. Techniques for application of vegetation classification in management of natural areas and in use of undisturbed areas as a comparison to disturbed areas	**(0/0/1)**
Subtotal - Part B	**(19/11/7)**
C. APPLICATION	
1. Mapping of vegetation to include both current and climax potential vegetation (and site factors)	**(2/0/0)**
2. Compatible inventory methods to integrate vegetation and soils as a basic resource stratification for planning	**(3/1/0)**
3. Define mangement needs and the data required to meet them and integrate into uniform workable inventory procedures	**(1/1/0)**
4. Test the risk and consequences of misclassifications	**(1/0/0)**
5. Development of a "holistic" approach to land management	**(0/1/0)**
Subtotal - Part C	**(7/3/0)**
D. EDUCATION	
1. Education and training for all users of classifications (concepts, application, and acceptable interpretations)	**(23/11/6)**
Subtotal - Part D	**(23/11/6)**
E. ADMINISTRATION--ALL ORGANIZATIONS AND AGENCIES	
1. Need agreement on desired vegetation classification system--and then, a commitment (funding) to develop it	**(0/2/4)**
2. Increased cooperation/coordination among agencies (and support service) in classifying vegetation	**(1/3/2)**
3. Provide means to enhance communication among those involved in vegetation classification (workshops, etc.)	**(1/1/0)**
4. Get research organizations back into vegetation and land classification	**(1/0/0)**
5. The only realistic way to collect enough data to model and classify all the successional pathways is for management to be committed to collection of this data as part of their normal inventory and management	**(0/0/1)**
Subtotal - Part E	**(3/6/7)**
Grand total	**(122/70/29)**

TOTAL R = RESEARCHERS (Scientists, classifiers, educators): 59
TOTAL U = USERS (Managers and staff specialists): 34
TOTAL N = NOT SPECIFIED: 15

TOTAL RESPONSES: 221
TOTAL RESPONDENTS: 108

Applications--To develop applications for resource managment, we are asking a lot of management specialists to go out and become ecologists and then link it together. Fortunately, managers and even scientists from other disciplines can learn to identify habitat types as a part of their routine field procedures. But, how do you pull all this information together? There are concepts and techniques that really have not been applied to this field. Methods that are used to summarize existing knowledge, such as Delphi or other group consensus techniques, may help meet the needs. New developments in the field of expert systems offer promise to help meet these needs. Is this a place for research to help meet these needs in an efficient manner?

Training--In regard to training, there is a real opportunity for educators, scientists, and management to jointly develop formal continuing education programs to meet the needs of the users. Several programs are in existence that should be continued and new cooperative education programs could be developed.

Similar thinking and planning needs to be applied to the other needs that are listed. However, expecting to receive a massive budget to meet all those needs that we listed is not really going to do it. It is going to come down to the concept of really wanting to see it happen--with professionals who want to do it, and other professionals providing the support to make it happen--not just saying that it is someone else's job. We all could have a hand in this.

There is a lot of work to be done. One person can not do it all. This symposium has been a demonstration of what a lot of people can do, even if not formally working together. The proceedings clearly demonstrates that we have come a long way. If we want to go further, if we really want to make this tool serve the end that foresters have agreed it could serve--not an end in itself, but as a means to an end--we must individually and collectively use our own professional enthusiasm and influence toward that goal (and everyone here has professional influence).

The support for revising the Daubenmires' (1968) types came from a few habitat type users in Idaho, working on the ground, who said they would really like to see some of the broader types subdivided. That support came from a very few individuals who let that need be known through administrative channels to the point where the USDA Forest Service decided to finance it. This gave Cooper and others (1987) the opportunity to initiate sampling and make substantial improvement in the classification.

It has been really exciting to come back and see what has happened--to see how this program has grown--to see the constructive efforts to build upon existing foundations. I wish us well in meeting the challenges ahead.

REFERENCES

Allen, B. H. 1985. Ecological type classification for California: the Forest Service approach. Gen. Tech. Rep. PSW-98. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, 8 p.

Cooper, S. V.; Neiman, K. E.; Steele, R.; Roberts, D. W.; 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington Agricultural Experiment Station. 104 p.

DOES A SYMPOSIUM HAVE AN AFTERLIFE?
THE COMMITTEE'S VIEW

Kenneth E. Neiman, Jr., and Kent E. Houston

ABSTRACT: The goal of this symposium was to bring together natural resource professionals from diverse fields of interest for the express purpose of discussing the current state of land classifications based on vegetation and their applications to resource management. The organizing committee perceived a need for interaction between resource managers and researchers and a need to reemphasize and refocus the direction of land classification studies. This paper summarizes the concerns of symposium speakers for current and future usage of vegetation-based classifications. A steering committee is proposed as a centralized coordinator for technology transfer and interagency research. Priority research/management projects are proposed for succession modeling, soil-plant community relationships, and effects of management practices on successional vegetation pathways.

INTRODUCTION

The purpose of this symposium was for the first time to bring together natural resource professionals from diverse fields of interest to discuss the state of western North American land classifications based on vegetation. We believed that a wide variety of applications were being used with only local dissemination of results and problems, thus limiting their effectiveness. Clearly, resource managers and researchers could benefit from exposure to recently completed and newly instituted empirical and theoretical research. We wanted to review the history of these land classification systems, the current status of development, and current applications in research and resource management. The gathering of interested parties for 3 days of discussion and mutually beneficial constructive criticism, though very worthwhile by itself, had a more important goal--the initiation of long-term ecological direction and coordination among land management organizations, academic institutions, and research units.

With the increased emphasis on multiple use of highly diverse resources, a common land classification system would greatly facilitate communication, the extrapolation and exchange of data, and development of multidisciplinary management guidelines. The symposium committee deliberately arranged most of the sessions to have minimal specific subject orientation. The success of this approach illustrated one of the most important advantages of vegetation-based classification systems--they provide a common link or language between all natural resource disciplines.

Forty-three formal papers and 30 posters were presented at the symposium. There were 241 registrants, including resource managers, administrators, educators, and researchers from 18 States, British Columbia, and Alberta. Their interests and expertise encompassed the fields of forest, range, watershed and wildlife management, soil science, natural area conservation, ecosystem modeling, and other related fields.

CLASSIFICATION AND BIODIVERSITY

During the last 20 years, increasing emphasis has been directed toward protecting and maintaining biodiversity, not only in the United States but worldwide. A number of Federal and State acts give direction and emphasis to this activity in the United States. A knowledge of species, plant communities, and habitat requirements of plants and animals is essential for protection and maintenance of biodiversity. Inventories of plant and animal species, plant associations, and seral communities are used by Federal and State land management agencies, The Nature Conservancy, and State heritage programs to determine where to focus their efforts. Classification of climax plant associations and seral communities is essential to help explain species requirements and distribution. Development of plant association and seral community classifications and the appraisal of rarity and condition of species, plant associations, and seral communities provide a means for management to protect and maintain biodiversity.

One common problem with many recent classifications, primarily developed to aid land managers, is that they focus on "important" community types and often neglect rare and imperiled types. Because they are rare, some community types may have been missed or bypassed in the sampling from which the classification was developed. However, some classifications are noteworthy in their

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Kenneth E. Neiman, Jr., is Forest Ecologist, Resource Analysis and Management, Seattle, WA; Kent E. Houston is Soil Scientist, Shoshone National Forest, Cody, WY.

attention to "very minor" and "incidental" communities. All who develop classifications should be encouraged to include not only the large and important but also rare and incidental community types. These latter communities may be in greatest need of protection and maintenance. Classification is the basis for identification, protection, and maintenance of biodiversity.

MAPPING AND INFORMATION STORAGE

Mapping of habitat types or plant associations is not merely the identification of land resource units, it is the development and recording of a basic understanding of the relationships between vegetation communities and their environment. At present there are no uniform standards for mapping habitat types or plant associations. Soil mapping has been a major project throughout the world and much can be learned from the techniques that have been refined over the years. Since soil and vegetation are both related to soil forming factors, it would appear that vegetation mapping techniques could use soil surveys as a template to develop and standardize methodology.

The advent of Geographic Information Systems and refinements in remote sensing techniques have revolutionized the storage, analyses, and uses of all forms of map data. Added to this is the computer storage of timber stand inventories, regeneration analyses, stand histories, current cover types, and numerous other stand characteristics needed for development of silvicultural prescriptions. These computerized data handling systems, when combined with artificial intelligence software that is being developed, will make highly sophisticated resource information and its analysis readily available to land managers.

TIMBER

Three equally important elements were originally envisioned in the development of vegetation-based land classification systems for the forests of the Intermountain West (Wellner, this proceedings). These same elements are also found to be of prime concern in all other vegetation-based classification projects being conducted throughout western North America. Habitat type or plant association classifications on a district-by-district or forest-by-forest basis, each developed by a different group of people having highly variable backgrounds in plant community ecology, has been demonstrated many times to be self-defeating. Therefore, the first task was the development by plant ecologists of classification systems based on climax or long-term stable plant communities occurring across broad geographic boundaries. This development of uniform classifications was given high priority because representative natural climax stands were becoming less frequent due to timber harvesting operations. The second element was production of secondary successional plant community classifications and stand development pathways. These would aid the prediction of plant community responses to disturbance and the sequence of events over time following known treatments or natural disturbances. The third element was development of community-specific productivity, silvicultural, and other management implications. While many locally specific implications are known, their delineation and investigation have been random and there has been no systematic cataloging or dissemination of information.

A major component of the perceived need for this symposium was to develop a renewed interest in completing and continuing this three-part program. A major portion of the first approximation--baseline classification work for the western United States and Canada--has been completed. Second approximations based on increased data sets and improved analysis techniques are beginning to be published. Development of successional classifications has shown that further delineation of climax communities is both possible and desirable. An intensive program of successional classification is being conducted for the forests of central Idaho. But all other programs for updating primary successional or developing secondary successional classifications have been halted or are being conducted on a very limited basis. To increase efficiency and to be of the most benefit to resource managers, successional work should be performed in a unified manner over a large geographic area by highly qualified ecologists. The Intermountain Research Station, Forest Service, U.S. Department of Agriculture, program in central Idaho and the National Forest System's Regional Ecology programs of long-term, in-place Area or Forest ecologists should serve as models for conducting these studies. The commitment of personnel and money is not trivial, but the practical benefits are extremely large. The knowledge gained from successional classifications and silvicultural implications can generally be put into immediate use.

RANGE

Papers presented in the area of range resources reflected the general acceptance of the need for classification of ecosystem units as a basis for sound management. While classification of range vegetation is still weak in certain regions, there is evidence of accelerated progress during the past decade, due primarily to increased interest and support by the major land management agencies.

Differences in understanding the relationship of classification units such as series, habitat types, plant associations, ecological sites, or range sites, plus lack of information on seral vegetation as related to its climax state, were cited as examples of current problems in rangeland classifications. Desire for a uniform system of classification was stressed, particularly by Bureau of Land Management representatives. The national soil classification system was cited as a potential model for such an endeavor.

TRAINING

Education and training of personnel involved with vegetation-based land classification systems is of considerable concern. A survey of professional foresters and forestry schools from the Far West revealed several significant points:

1. Field crews are not adequately trained to collect vegetation classification data.
2. A preponderance of bad data collected by poorly trained personnel is used in permanent forest inventory data bases.
3. Professional foresters and advisory staff both were judged weak in understanding the complexities of vegetation-based land classification systems.

Based on the survey results, there appeared to be a general feeling that all levels of the forestry profession lack sufficient understanding of the conceptual bases for vegetation-based land classifications, and thus their ability to interpret, extrapolate, and apply these classifications is seriously compromised. Both forestry students and agency personnel need more and better education in classification systems. Although they were not included in this survey, it is assumed that similar results would be found within the ranks of other natural resource disciplines.

WILDLIFE

Habitat relationships of many wildlife species are not keyed to plant community classifications based on floristics and site potential, but rather to stand characteristics such as stand structure, canopy closure, understory density, and other characteristics more indicative of available cover and forage. Nevertheless, a knowledge of site potential for plant species composition and quantity can aid in predicting stand characteristics that relate to wildlife habitat requirements. Investigations of climax/seral relationships must be expanded, since successional stages provide important forage and cover for a variety of species. Delineation of successional pathways within habitat types and plant associations should also be an important effort in wildlife habitat research and management. Efforts to relate habitat preferences to classifications of seral stages within habitat types will help in predicting effects of habitat change on wildlife populations.

RECOMMENDATIONS

In organizing the symposium, the committee found that the various disciplines are not significantly different in their approach to land classification. Converging most of these classification systems into one system seems reasonable and desirable. Terminology and classification systems should be standardized, at least for western North America.

Because of the complexity of interrelated studies and the need to integrate the efforts of managers with researchers within many of the studies, the symposium committee believes that a steering committee should be instituted as a centralized coordinator of interagency land classification efforts. In addition to performing coordination of interagency research and monitoring administrative study overlap, this committee could facilitate technology transfer, act as a clearing house for the sharing of research results and management applications through symposia and workshops. This group could establish an information storage and retrieval system for land classification by vegetation, making it possible to highlight gaps in current information and serve as a guide for future investigations. Such a steering committee must be broadly based geographically and philosophically if it is to serve effectively. We believe there is a need for both a core group, which would perform the major functions of a steering committee, and a "loose" or oversight group, comprised of persons having widely dispersed professional and geographic backgrounds. Initially, the steering committee could be composed of interested people from the original symposium committee and other persons who would serve with them. This is not being proposed as a closed committee. Anyone desiring to participate will be more than welcome.

Many speakers at the symposium indicated a need for research projects in their area of interest. A conservative compilation of research and data analyses that are currently addressing these needs, or that need to be instituted, easily exceeds 50 projects. We suggest three subject areas for consideration as priority research/management projects: succession modeling, soil-plant community relationships, and effects of management practices on successional vegetation. Each of these subjects should be subdivided into multiple projects. All projects should be planned and conducted jointly by research and management personnel.

At least 16 papers and posters dealing directly with secondary succession processes or modeling efforts were presented at this symposium. The one consistent trait in most current models is the narrow applicability as to geographic region and group of plant associations described, or subject area of use (such as silviculture, wildlife habitat, or fire management). High priority should be assigned to additional successional community classification and modeling projects. The amount of data collection and analysis needed to provide successional classifications for only the most prevalent and economically important plant associations occurring throughout the western United States, British Columbia, and Alberta would keep many teams of ecologists busy for years to come. We also find that, although many succession models have been developed recently, few of them have undergone intensive field verification by qualified ecologists. Feedback to researchers has primarily been from satisfied users; managers who try the model and find it wanting, simply abandon its use.

Similar to the interest in succession modeling, a need for soil-plant community relationship studies was discussed. One formal paper and three posters dealt directly with this subject, while a dozen or more of the papers and posters focused attention on the need for baseline data and research. Several speakers recounted observations of variable successional responses to application of the same silvicultural prescription within a single habitat type or plant association. The only difference they could account for between sites was in the soil supporting the communities. Research projects should be developed that determine the relationship within or between soils and plant communities, and that determine if these relationships have management significance. It is our opinion also that plant community and soil resource classifications should be developed concurrently. The resulting baseline data and classifications would be far more useful and precise than those developed independently.

The third area we feel should have a high priority is the compilation of plant community responses to specific management practices. Where classification systems are too recent for this information to be readily available, documentation and studies of the effects of management practices on successional vegetation should be implemented. Although studies in this subject area run parallel to the succession modeling discussed above, we feel that separate projects are needed with emphasis directed toward identifying community responses to specific kinds and degrees of management applications under varying site conditions. We view this project as requiring an applied research approach rather than the more conceptual emphasis needed in computer modeling of succession. This group of studies is one in which resource managers must participate from the beginning and at a level of personnel involvement not previously afforded managers due to the research nature of the project.

A major effort should be made to develop closer links between researchers and field management personnel. At present the gap between available research data and their utilization seems wide, and it is not being fully bridged by conventional extension efforts. To more efficiently conduct long-term cooperative studies, changes should be instituted in Federal and State agency regulations governing the direct involvement of resource managers and the use of management funds for what are ostensibly research purposes.

CONCLUSIONS

We feel a truly successful symposium must have an afterlife. To this end, we recommend that a committee be formed to begin the task of coordinating technology transfer through additional symposia, workshops, and literature distribution and to coordinate research related to habitat types and plant associations. This effort must be extended to all concerned parties through their participation, not just through a restricted group of interested individuals. Greater emphasis is needed on field-oriented workshops and short courses in which interested user groups can focus on the underlying conceptual basis as well as the applications of classifications of specific wildland ecosystems.

A number of studies should be developed, funded, and completed if management's need for successional information is to be met in a timely manner. Plant ecologists should conduct the required studies with a committed, formal participation of resource managers. Studies conducted through cooperative efforts of researchers and managers would achieve results more quickly and would generally be more readily accepted and used by natural resource managers.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the members of the symposium committee listed in the foreward of these proceedings for their contributions to and critiques of this paper, and for their generous contribution of time, effort, and ideas in the creation and execution of this symposium.

POSTER PAPERS

Synopses of 24 Posters Shown at the Symposium

ECOLOGICAL LAND CLASSIFICATION IN CANADIAN ROCKY MOUNTAIN NATIONAL PARKS

Peter L. Achuff

Ecological Land Classification is an integrated resource inventory method which uses landform, soils, vegetation and wildlife information presented in both report and 1:50,000 map form. These land classifications have been prepared for the six Canadian Rocky Mountain National Parks of Banff and Jasper (Holland and Coen 1982), Kootenay (Achuff and others 1984a), Mount Revelstoke and Glacier (Achuff and others 1984b) and Yoho (Coen and Kuchar 1982). A three-level, hierarchical land classification was developed using the Canadian landform and soils classification systems plus a vegetation type classification developed by project scientists. The three levels, from highest to lowest level of generalization, are: Ecoregion, Ecosection and Ecosite.

Ecoregion separations are based primarily on vegetation physiognomy and species composition which reflect macroclimate. Montane, Subalpine and Alpine Ecoregions are recognized. The Subalpine Ecoregion is divided into Lower Subalpine and Upper Subalpine based on vegetational characteristics reflecting macroclimatic differences.

Ecoregions are divided into Ecosections based on broad landform, drainage class and soil differences. Landforms are composed of ten genetic materials which are divided into genetic material units based on textural and chemical (calcareousness/pH) differences. Ecosections are divided into Ecosites based on landform, soil and vegetational differences of smaller magnitude than those used at the Ecosection level. Ecosites plus nine Miscellaneous Landscapes (for example, colluvial landslide, rock glacier) are the map units delineated. The landform, soil, vegetation and wildlife characteristics of each Ecosite are described in the reports and map legends. Wildlife information includes the importance of each Ecosite for common animals and descriptions of breeding bird communities and small mammal associations, as well as species and watershed area accounts (Holroyd and Van Tighem 1983; Poll and others 1984; Van Tighem and Gyug 1984). Importance ratings for wildlife in each Ecosite were derived from field data on actual use (for example, from pellet counts and browse use ratings for ungulates or call count transects for breeding birds) rather than by inference from habitat features.

Ecological Land Classifications have been used successfully for a variety of planning and management purposes including: environmental impact assessment and monitoring, fire management, facility planning, forest insect and disease management, trail location, rare species management, archaeological research, range management for both wild and domestic species, and bear/habitat evaluation and management.

REFERENCES

Achuff, P.L.; Holland, W.D.; Coen, G.M.; Van Tighem. K., eds. 1984a. Ecological Land Classification of Kootenay National Park, British Columbia. Vol. I: Integrated resource description. Publication M-84-10. Edmonton, Alberta: University of Alberta, Alberta Institute of Pedology. 373 p.

Achuff, P.L.; Holland, W.D.; Coen, G.M.; Van Tighem, K., eds. 1984b. Ecological Land Classification of Mount Revelstoke and Glacier National Parks, British Columbia. Vol. I: Integrated resource description. Publication M-84-11. Edmonton, Alberta: University of Alberta, Alberta Institute of Pedology. 261 p.

Coen, G.M.; Kuchar, P. 1982. Biophysical (ecological) inventory of Yoho National Park, British Columbia, Canada. LRRI Contribution 82-20. Edmonton, Alberta: Agriculture Canada, Land Resource Research Institute, Soil Survey. 92 p.

Holland, W.D.; Coen, G.M., eds. 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Vol. II: Soil and vegetation resources. Publication SS-82-44. Edmonton, Alberta: University of Alberta, Alberta Institute of Pedology. 540 p.

Holroyd, G.L.; Van Tighem, K.J. 1983. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Vol. III: The wildlife inventory. Edmonton, Alberta: Environment Canada, Canadian Wildlife Service. 691 p.

Poll, D.M.; Porter, M.M.; Holroyd, G.L.; Wershler, R.M.; Gyug, L.W. 1984. Ecological Land Classification of Kootenay National Park. Vol. II: Wildlife resource. Edmonton, Alberta: Canadian Wildlife Service. 260 p.

Van Tighem, K.; Gyug, L.W. 1984. Ecological Land Classification of Mt. Revelstoke and Glacier National Parks. Vol. II: Wildlife resource. Edmonton, Alberta: Canadian Wildlife Service, 254 p.

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Peter L. Achuff is Adjunct Professor, Department of Forest Science, University of Alberta, Edmonton, Alberta, Canada T6G 2H1

FEDERAL AND STATE ECOLOGICAL SITE CLASSIFICATION:

TWO APPROACHES WITH COMMON GOALS

Barbara H. Allen and David V. Diaz

ABSTRACT: Ecological site classification is being conducted by the California Department of Forestry and USDA Forest Service in California. Although these agencies have similar goals, their approaches are very different. The Forest Service' focus is to classify all vegetation on National Forest System lands, while the State's focus is hardwood rangeland of all ownerships. The Federal effort involves on-the-ground specialists collecting new information and developing the classification over 3 to 7 years, while the State effort focuses on the use of existing plot data to develop an ecologically based cover type classification system in 18 months. Goals, objectives, approaches, and expected products are described.

INTRODUCTION

Classifications are tools for organizing, labelling, storing, and retrieving various kinds of data. Ecological classifications are particularly useful in resource management because they integrate diverse attributes of vegetation, soils, and landforms into homogeneous areas. These areas are united by complex ecological inter-relationships and common predictable responses to management inputs. The process of developing these classifications most often involves the collection of environmental and vegetation data over specific geographic targeted areas. The process also involves the commitment of skilled ecologists to become intimately familiar with the ecosystems being studied. The results are detailed site-specific descriptions for areas bound together by common vegetation, soil(s), landform(s), productivity, and expected response to management. For managers, the results are a common language for describing land and specific information for improving management decision making.

THE PROBLEM

The development of an ecological type classification system by the Forest Service in California began in 1983. Prior to this time several factors worked against the development including (1) a perceived lack of need, (2) a belief that California's vegetation was too diverse and complex, and (3) an aborted and expensive effort attempting to do ecological type classification which discouraged managers.

By 1983, the USDA Forest Service in Region 5 was five years into Forest Land Management planning required by recent Congressional mandate. The agency's managers were intimately aware of the difficulties arising from being restricted to using uncommon land labeling systems, uncommon inventory units, and predictive information that was not ecologically based. These data were essential for planning models such as FORPLAN and to develop site prescriptions where resource demands increasingly conflicted and personnel, unfamiliar with the ecosystems, were forced to make management decisions. The days of depending on a person's 30 years of familiarity with a particular place were rapidly disappearing. These factors led to the initiation of an ecologically based land classification program in the Region in 1983, by appointing a Regional Ecologist program leader, who was to be guided by an interdisciplinary resource advisory committee.

Meanwhile, resource personnel working for the California Department of Forestry (CDF) watched the Forest Service classification effort with interest, keeping informed of the effort through participation in a coordinating group called the Interagency Vegetation Classification Committee. During this time, the State's Forest and Rangeland Resource Assessment and Planning staff (FRAAP) was preparing a statewide assessment of natural resources. Common problems with lack of common labeling systems, lack of compatible inventory data, and lack of research information on site response to management made State managers fully aware of the need for an ecologically based classification.

During the period that FRAAP was making its assessment, the management of the State's hardwood rangelands, which occupy approximately 3 million hectares in California, spread over 52 of 58 counties, became a land use issue and the focus of much attention from the State Board of Forestry, private ranchers, and resource and environmental groups. Rapid population growth in

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Barbara H. Allen is Assistant Professor, Dept. Forestry and Resource Management, Univ. California, Berkeley, CA; and David V. Diaz is Regional Ecologist, USDA Forest Service, San Francisco, CA.

California has caused hardwood rangeland conversion from open space to housing and agriculture, loss of wildlife habitat, and an increased cutting for fuelwood. This, coupled with documented hardwood species regeneration problems, the lack of a unifying classification or descriptions of hardwood site potentials, and an immediate threat of State-imposed regulations on the use of the hardwood resource, 85 percent of which is in private ownership, moved the State to establish an Integrated Hardwood Management Program. The Program is designed to develop, administer, and monitor research, education, and technology programs to improve knowledge of the hardwood resource. The development of a hardwood ecological site classification system was one such funded research project.

GOALS AND OBJECTIVES

Thus the Forest Service and State of California had fundamentally similar problems and common goals for the development of an ecological classification system. The goals can be summarized as:

1. Improve communication among resource managers through use of a common labeling system and site descriptions;
2. provide unifying framework for the organization of other classifications, inventory, and mapping systems; and
3. improve the information available for the resource managers' decision making, giving them predictive ecological information.

Objectives of the two agencies differ only slightly. The Forest Service effort focuses on all National Forest System lands in California including the development of ecological type classification for all vegetation types. The classification is expected to link diverse resource inventories and provide baseline information for future Forest Land Management Planning and RPA Assessments. The Forest Service plans to develop seral stage descriptions, provide information on site response to management, and develop methods to determine ecological status and resource rating guides. The State and the Forest Service want to increase the application of theoretical and applied research results through the use of the ecological site classification.

The State's focus is on all state, federal and privately owned hardwood rangelands. The development of the classification will assess available ecological and management information, provide for a statewide hardwood rangeland data base, and establish methodology for refinement and field testing, and future evaluation.

APPROACHES

The Forest Service and State approaches to the development of the ecological site classification are quite different. The Forest Service is collecting new site-specific data in two phases, a reconnaissance phase of approximately 3-4 years followed by an intensive phase of another 5 to 7 years (fig. 1). This two-phase strategy evolved after review of existing plant community and habitat type approaches used in other parts of the country and with input from resource specialists in the Forest Service. The approach stresses detailed field data collection and intimate resource familiarity by an ecologist/soil scientist team. Resource manager review of products is an integral part of the process.

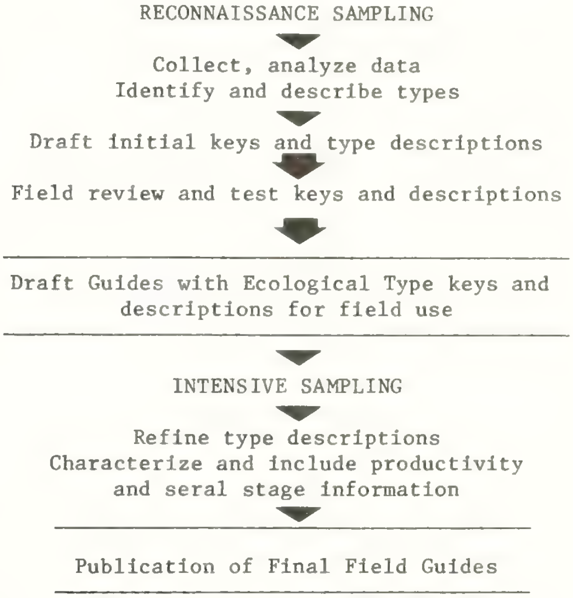
RECONNAISSANCE SAMPLING
Collect, analyze data
Identify and describe types
Draft initial keys and type descriptions
Field review and test keys and descriptions
Draft Guides with Ecological Type keys and descriptions for field use
INTENSIVE SAMPLING
Refine type descriptions
Characterize and include productivity and seral stage information
Publication of Final Field Guides

Figure 1--The six major steps in the development of the Forest Service Ecological Type classification system are carried out by a team of ecologists, botanists, and soil scientists.

The State approach took the form of a contract awarded by CDF to the University of California, Berkeley. By agreement, the ecological site descriptions for the hardwood rangeland resource must be completed in 18 months. The timeframe necessitates the use of available plot data collected in California by different agencies over the last 30 years. Three data sets will be used: the Pacific Northwest Station Forest Inventory data, the California Soil/Veg Survey data and the Soil Conservation Service Range Site data. A public workshop scheduled for winter 1987 will provide the forum for reaching consensus on classification criteria. Site descriptions will be developed for field testing by resource experts. Hammon, Jensen, and Wallen, an Oakland-based environmental consulting firm, will develop methodology for computerizing the classification descriptions and mapping classification units.

PRODUCTS

Forest Service ecological type descriptions, in draft stage at present, contain information on the vegetation, landforms, and soils. When completed they will provide productivity of the site for different resource uses; expected site response to management, such as fire, grazing and timber harvesting; seral plant communities; and relationships to other ecological types. At a site location, the information will be accessed through the use of a dichotomous key. Sites will be identified in the field through knowledge of a few indicator plants and use of the dichotomous key. A representative photograph of each site will be included in the field guides.

The State hardwood descriptions will be broader, limited by the kind of plot data used in their development. Because the data in the three data sets were collected by different and independent investigators, it will be difficult to distinguish potential natural vegetation from seral stage plant communities. Although the focus is on mature hardwood stands, the type of data and the short timeframe for field testing seem to require the use of the term "cover type" until further evaluation proves the successional placement of a type. Information on response to management and predicted seral plant communities will come from past and current research, where the research unit was labeled with this system's identified types. Future research and the Forest Service ecological type work in the hardwood rangelands with National Forests will provide additional information to refine and update the State's hardwood rangeland classification. A photograph, representative of each site, will be included with the description.

A MULTILEVEL RESOURCE INFORMATION SYSTEM USED AT THE FLATHEAD NATIONAL FOREST

Stan Bain

ABSTRACT: Flathead National Forest encompasses approximately 2.6 million acres in northwest Montana with Forest headquarters in Kalispell. Flathead National Forest is confronted with the problem of managing an area with diverse concerns. With the increasing pressures to provide better management of Forest resources with reduced budget and to balance the needs of timber, wildlife, and recreation in an economically and ecologically sound manner, it is increasingly important that map and tabular information be available to resource managers in an efficient manner. Flathead National Forest has adopted the use of Geographic Information System and Image Processing technology along with Remote Sensing using Landsat data, to construct a Multilevel Resource Information System as one means of supplying information in a timely and economical fashion.

INTRODUCTION

The combination of computer-assisted Geographic Information System (GIS) and Remote Sensing (RS) satellite data provides spatial overlays necessary for analyzing multiple layers of information. The GIS produces results in minutes, whereas conventional methods of making overlays and maps for analysis may take weeks, months, and years to complete. GIS uses digital data in coordinate form to produce data planes (layers) which are maintained in the system as individual databases. Through computer manipulation, any number of planes may be combined with assigned parameters to produce a variety of map and tabular results. The speed and power of computer manipulation is especially valuable for sensitivity testing in the iterative process of alternative generation.

Establishing in-house GIS and Image Processing (IP) expertise and maintaining in-agency project management were identified as vital success factors in creating an operational Multilevel Resource Information System (MURIS) program. Flathead National Forest (FNF) personnel were trained in GIS and IP system use through the Digital Image Analysis Laboratory at Washington State University Computing Service Center (WSUCSC). Throughout the project, GIS and IP have been performed with WSUCSC's VICAR/IBIS image processing system via telecommunication from FNF agency office. VICAR/IBIS provides many processing alternatives for combining, overlaying, and analyzing multiple raster-formatted data planes, using image processing algorithms to manipulate spatial data mathematically.

THE FNF OPERATION

This MURIS effort is unique in two respects: the FNF has not acquired any additional computer hardware or software to reach the present operational stage; and, FNF personnel have performed all project work rather than having the project contracted to an outside service organization. In the future some of the basic digitizing may be contracted under direct supervision of Forest personnel, as the major work of digitizing must be done at the Forest level to ensure fully developed diversified data planes. The Landsat classification, map digitization, data management, project implementation, coordination and applications through data plane manipulation were done by Forest personnel. As the database for each ranger district reaches the operational stage, personnel at the ranger district receive training in data plane combination and query techniques enabling data manipulation capabilities at the ranger district office. Additional capabilities will need to be added to the present computer facility at Forest headquarters to display and optimize MURIS capabilities.

When MURIS was evaluated by Forest managers, speed and accuracy of GIS and IP product generation met all acceptability criteria. Operational MURIS databases are now being constructed and the completion of Landsat classification and ground correlation will be completed next year for the Forest in its entirety.

APPLICATION CATEGORIES

In the operational phase of the MURIS, applications fall under three basic categories; inventory, modeling, and monitoring. The Landsat classification, with the recent refinement, satisfies the need for a plant community map. The convenient quantification of area and length

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Stan Bain is Cartographer, USDA Forest Service, Flathead National Forest, Kalispell, MT.

provides needed inventories for surface waters, roads, trails, and other data planes. When digitally overlain, multiple data planes can be applied to inventory site-specific parameters, such as the distribution and abundance of grizzly bear food types within a particular drainage. Derivative inventory data can also be produced from original inventory planes. These data planes contribute a comparative means to address questions of human influence on the environment and wildlife.

These simple inventories provide the bases for modeling efforts that involve manipulation of multiple data planes. Modeling potential elk calving location is critical to management of that species. Other modeling techniques are fire behavior modeling, modeling erosion impacts, identification of trail hazards, modeling trail and campsite locations, and timber stand inventories and others.

Each geographic plane, whether derived through inventory or modeling, serves as a baseline by which changes can be detected and measured in the future. Monitoring further serves to test hypotheses and the validity of models over time. Monitoring will also provide an understanding of long-term natural processes such as plant succession after fire and the progression of widespread forest pathogens.

THE FUTURE

Our goal is to continue with our relationship with WSUCSC in further Landsat classification and to provide a in-house GIS and display system for analyzing alternatives. Applying a full range of application from the Forest, MURIS will allow planners and managers to analyze alternatives on critical lands where vegetative manipulation and other project proposals can achieve the desired objectives of land management economies and efficiencies.

LANDSAT CLASSIFICATION AND FIELD CORRELATION METHODS FOR VEGETATION CLASSIFICATION USED AT THE FLATHEAD NATIONAL FOREST

Stan Bain

ABSTRACT: Landsat, one of the most important achievements of the U.S. space program, has the capability to perform inexpensive world-wide surveys of global conditions and resources. But Landsat alone cannot achieve resource survey without support data from other technologies such as Geographic Information System (GIS) technology, as well as accurate location of field plots and field data. A multiclustering technique with an intensive spectral analysis and editing method is performed to provide a statistics set for a spectral classification. With the use of field data, a strata requirement is formulated to use other spatial data planes to correlate field data to the Landsat spectral classification. With the spectral classification and the formulation of other spatial data planes, a detailed vegetation Landsat classification is performed. With support technology, capabilities, and correlation with field data, Landsat can provide an accurate, economical, and efficient method for mapping vegetation for a wide range of management applications.

INTRODUCTION

There are several very important steps to accurately map resource information to the level of most project applications from Landsat data. In our approach, the analysis is made using VICAR/IBIS (Video Image Communication And Retrieval, Image Based Information System) (Hart and Wherry 1984), at Washington State University Computing Service Center (WSUCSC) as the primary processing system. VICAR/IBIS, a batch processing system, with localization of the input/output operation and with many parameters, provides many processing alternatives. The IBIS extension to VICAR adds significant capabilities for combining, overlaying and analyzing multiple data sets, which is critical to this project. The raster format data can be spatially manipulated mathematically using digital image processing algorithms (Jaffray and others 1984) in the classification of spectral data.

METHODOLOGY

In this project a methodology similar to the multiclustering technique described by Hoffer (1979) was used with a few modifications in the construction of the final classification statistics set. This guided clustering methodology is basically a supervised approach with one very important modification: unsupervised clustering is done within small training areas to reduce spectral nonuniformity within the final classes. Essentially the same procedure is used in a supervised approach in selecting training areas. Some care needs to be taken to ensure spectral purity where possible to make fine distinctions with the Landsat data between species. Each training area will produce several spectral classes in a statistics file. Several statistical files will contain several hundred sets of statistics which need to be edited and combined into one statistical file for classification.

The analysis of the statistics and the final statistics set will make or break the final vegetative classification. It is very important in the analysis of the statistics, especially in the timber areas, to keep the covariance as small as possible, to only pool clusters that are exactly the same, and to not pool clusters that have a small covariance with clusters with large covariance. All spectral classes must be compared with spectral separability of other spectral classes, and by analyzing the covariance and the separability, the confused classes can then be deleted in the editing process. Spectral plots between MSS band 5 and MSS band 7 will aid in this editing process. A scatter plot showing pixel populations in a three-dimensional scatter diagram is very helpful to ensure that the final statistics will cover the full range of spectral data when compared to the spectral plot. The final statistics set may contain as many as 80-140+ statistics to be used in the final spectral classification. Remember when doing a Landsat classification you are mapping spectral data and not vegetative data.

Once the spectral classification is complete, the image is registered to a UTM (Universal Transverse Mercator) map projection. This is done by selecting several control points, lines, and samples on the image and corresponding points on USGS 7 1/2 minute quad by using International Imaging System, a system 511 image display system at WSUCSC. Map control points are digitized to determine the UTM values of each point.

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Stan Bain is Cartographer, USDA Forest Service, Flathead National Forest, Kalispell, MT.

Control points are evaluated and those in error are edited out until a residual of less than one pixel is obtained. Using the control point file, a geometric transformation is performed registering the Landsat spectral classification to UTM, 50 meter pixel image. This image is now registered to other data planes that will be used in the final stratified classification.

It is also very important to be able to correlate ground plots with the spectral data. In doing so, the ground crews must be able to accurately locate the field plot within the spectral class. This is done after the spectral classification is completed. Flathead National Forest (FNF) personnel use the following procedure to produce a spectral map at a scale of 1:15840, sometimes referred to as a lineprinter map. Spectral classes of 6 pixels or greater are located on the spectral map to form spectral polygons. These polygons are then transferred to orthophoto maps, or aerial photography by stereo compilation methods. FNF personnel and contractors use the orthophoto maps and aerial photography products to locate their field plot within or close to the center of the spectral polygon. Basic photo interpretation techniques are used to measure the bearings and distances from a starting point or image point on the photo products to locate oneself within the spectral polygon.

Several plots are taken of each spectral class representing major elevation, aspect, and ecological relationships. A one-tenth-acre plot is taken that will represent the vegetation of the spectral polygon. Sometimes a "walk through" of the spectral polygon is performed before the plot location is determined to ensure the plot location will represent the spectral polygon. The walk through may reveal that more than one plot needs to be taken in the same spectral polygon to map the major difference in the vegetation. Within the plot location all vegetation is measured and timber stand data is recorded as well as other environmental features that will aid in the stratified classification of a confused spectral class.

All field data and spectral classes are entered into a data entry program on the Forest computer system. Through data analysis, Forest personnel can determine stratified requirements for each spectral class or classes and whether elevation, aspect, soils, etc. is needed to classify the spectral data into vegetative data for final classification (table 1).

A series of data planes may be needed to meet the stratified requirements. Elevation, aspect, and soils were mentioned above, but requirements may also include other spatial data. Not all of the spatial data planes need to be used for each spectral class. As an example, spectral class 1 may require only elevation zones to clarify the confusion of a vegetation class, or it may require several data planes to accomplish the task. Even a spectral class at a specific elevation zone and aspect may be combined to another spectral class on a specific soil type and aspect to make an information vegetation class.

Once the stratified requirements are determined for each spectral class, a computer job is set up using Geographic Information System (GIS) technology or look-up tables to classify the spectral data into a vegetation classification. This result can provide a very detailed legend and

Table 1--Spectral class and strata report

SPECTRAL CLASS (1)	ELEV (2)	ASP (3)	SLOPE (4)	HT (5)	STC (6)	FCC (7)	SP1 (8)	%	SP2 (9)	%	SP3 (10)	%
12	4000	S	10	450	SEED	0-10	PICO	10	PSME	10	XETE	40
12	4200	NE	35	690	SEED+	0-10	PICO	10	LAOC	30	ABLA	10
12	5900	SE	60	691	SAP	71-100	PICO	50	PSME	10	ABLA	10
12	6300	E	90	691	SAP	41-70	PICO	50	PIAL	10	ABLA	10
12	7000	SW	30		SEED+	11-40	ABLA	20	PIAL	10	XETE	60
13	3800	E	20	662	SAP	41-70	PICO	50	ABLA	20	PIEN	10
13	3800	W	50	662	SAP	41-70	PICO-	10	PIEN	30	PSME	20
13	4000	NE	0	663	POLE	41-70	PICO	20	LAOC	20	VASC	20
13	4000	NE	40	662	POLE	41-70	PICO	40	LAOC	30	VASC	20
13	4000	W	10	640	POLE	41-70	PICO	40	PSME	10	ABLA	10
13	4000	W	10	640	POLE	41-70	PICO	40	PSME	10	ABLA	10
39	4000	W	50	623	MATURE	71-100	PICO	30	LAOC	30	PSME	30
39	4000	W	80	691	MATURE	41-70	PICO	40	LAOC	10	PSME	10
39	4300	N	35	624	OLD	41-70	PICO	50	LAOC	10	PIEN	10
39	4600	SW	25	653	MATURE	41-70	PSME	40	LAOC	10	PIEN	10
83	3600	W	20	750	POLE	11-40	PICO	40	LAOC	10	CARU	70
83	6900	NW	20	850	POLE	11-40	PIAL	10	ABLA	20	PIEN	10

(1) spectral class from landsat classification, (2) elevation (3) aspect, (4) slope %, (5) habitat type, (6) structural class, i.e. seedling, mature, old growth, etc., (7) forest canopy closure %, (8) thru (10) vegetation species.

Table 2--Landsat vegetation legend

VEG CLASS (1)	DESCRIP. (2)	SP1 (3)	SP2 (4)	SP3 (5)	SP4 (6)	SP5 (7)	ST (8)	FCC (9)	HAB (10)	CLASS/ACC (11)
1	WATER									90-100
12	AGG	CROPS								90-100
33	CONIFER	PICO	LAOC	PIMO	VAGL	XETE	OLD	11-40	6	85+
36	CONIFER	PICO	PSME	PIEN			MAT	11-40	5	80+
54	SHRUB/CONF	ACGL	ALSI	LOAC	PIEN	ABLA	MAT	0-10	6	85+
185	HERBAC	SOIL	GRASS	PICO			SAP	0-10	6	85+
190	NON-VEG	ROCK	SOIL				N/A	N/A	N/A	90-100

(1) Vegetation class, (2) Cover type, (3)-(7) Species by dominance, (8) Structure; mature timber, old growth, etc., (9) Forest canopy closure %, (10) Habitat group, (11) Vegetation class accuracy determine by field plot, photo interpretation

classification then can be used for a wide variety of resource applications (table 2). This process can provide information such as species in order of dominance, crown density, and structure, as well as quantitative information.

VERIFICATION AND ACCURACY CHECKS

Verification and accuracy assessments are often required to achieve a predetermined level of accuracy; at the very least, users will want to know the level of accuracy associated with the finished classification so that they will understand how best to use it. With the use of this method of classification and ground correlation, the accuracy of the project can almost be determined or built into the classification process itself. Sometimes the confused spectral classes may require additional field plots or other stratified requirements to achieve the accuracy one requires.

Ultimately, a verification is needed to provide a degree of confidence and reliability in the classification. FNF uses several steps in checking the accuracy of the classification process. Each field plot, that was taken inside the spectral polygon is digitized and converted to an image. This image can then be overlaid on the final classification to check to ensure that the stratified requirements were met, and the field plot description correlates with the vegetation classification description. The system 511 at WSUCSC is used by displaying 512x512 images of the classification and visually checking the overall classification with aerial photos, timber stand maps, and other mapping records. Classes that are questionable are checked on the ground with a walk-through method or with additional ground plots if additional classification work is needed. Errors are corrected if project accuracy of 80 percent is not met. Accuracy level is assigned to each class which becomes part of the final legend (table 2). As the vegetative classification is used for application, such as in wildlife habitat mapping, fire group classes, or mapping old growth timber, the individual vegetative classes are combined into a cover class which greatly increases the accuracy.

CONCLUSION

With accurate field plot locations, and accurate field data, along with intensive cluster and spectral analysis and correlation, Landsat can provide a vegetation classification. The classification results can provide resource managers a GIS vegetation data plane containing species, forest canopy closures, habitat type groups, structure, and quantitative information such as timber volumes.

Landsat classification with GIS technology can provide forest managers vegetative information that managers can use in the analysis of Forest resources of timber, wildlife, fire management, and recreation in a economical and efficient method. This method, with a temporal Landsat classification, can monitor changes due to timber sales, plant succession after fire, and the progression of wide-spread forest pathogens. This system will provide important information to FNF to meet its management mandate and administer its Forest Plan (Proposed Forest Plan 1983).

REFERENCES

Hart, J.A.; Wherry, D.B., ed. 1984, VICAR/IBIS User reference manual, Volumes 1-4, Washington State University Computing Service Center, Pullman, WA. 876 p.

Jaffray, M.J.; Hansen, R.S.; Hart, J.A. 1984. A geographic information system for Spokane County. In: Proceedings, 22nd annual conference of the Urban and Regional Information System Association. 1984 August 12-15, Seattle, WA: 154-163.

Hoffer, R.M. 1979. Computer-aided Analysis of Remote Sensor Data---Magic, Mystery, or Myth? In: Proceedings of Remote Sensing for National Resources, University of Idaho, Moscow, ID: 156-179.

Proposed Forest Plan 1983. U.S. Department of Agriculture, Forest Service, Flathead National Forest, Kalispell, MT. 28 p.

A VEGETATION CONDITION APPROACH TO LAND USE PLANNING

R. Lee Barkow

ABSTRACT: Land use planning can be accomplished effectively by focusing on the vegetation condition necessary to produce the desired commodities or values. This planning process utilizes the difference between current and desired vegetation conditions and related productivity to identify opportunities for change. Successful land use planning will develop a strategy that will assist managers in moving from the current vegetation condition toward the desired condition.

INTRODUCTION

The purpose of land use planning is to make decisions that will accommodate various land uses and direct the management of a particular area. In doing so, it is important to accurately identify the proposed uses, the possible conflicts in accommodating each of the uses within a particular area, and develop alternatives to resolve the conflicts. Conflicts, either real or perceived, are the heart of all planning systems. Issues are usually portrayed by managers and the public alike as two or more land uses or values which appear to conflict within an area. Issues such as a conflict between livestock grazing and wildlife, and mineral development and recreation are common to most land use plans. When an issue is identified, the most common response is that there is in fact a conflict because the competing uses need the same resource base to sustain each use. There is not enough of a resource or land to go around. Conflict resolution usually revolves around selecting one use over the other or splitting the available land or resource between the competing uses. There is little attention or thought given to identifying what it would take to accommodate the competing uses in terms of describing the resource needed to accommodate all of the demand.

VEGETATION CONDITION CLASSES

When we, as professional land managers, and the public look at a given area, the first element of the environment that we focus on is the condition of the vegetation. We often make statements that relate to either the current condition of the vegetation resource or the desired condition of the vegetation which is different from the current condition. For instance, when we look at the quality of the water present, whether it is in a lake or a perennial stream, we often relate it to the condition of the vegetation within the drainage or watershed. We may identify a high sediment load and trace the cause to overgrazing, overcutting, or poor riparian vegetation.

Most proposed land uses or values can be placed within an identified vegetation condition that is optimum for the desired use. For instance, we can describe the optimum condition for winter range or escape cover for target wildlife species. We can describe the optimum vegetation condition for livestock grazing at various stocking levels. In addition, we can describe the optimum vegetation conditions for such activities as off-road vehicle use, dispersed recreation, and scenic quality. Granted, the optimum vegetation conditions are not the same for all activities or uses. But the point is that we can describe the desired vegetation condition for most proposed uses.

Similarly, we can describe the current condition of the vegetation and add it to the amount of activity or use that the vegetation is supporting. With this information, the difference between the current condition and the desired condition can be determined in straightforward terms.

RELATIONSHIP WITH CURRENT PLANNING PROCESSES

Planning from the perspective of a vegetation condition is easily accommodated within most current planning processes. The only requirement is to do some steps in a slightly different order. The following explores how this could work.

The first step in this planning process is to describe the current vegetation condition and the related productivity for each commodity resource or value for each non-commodity

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R. Lee Barkow is Chief, Planning and Environmental Coordination, Bureau of Land Management, Colorado State Office, Lakewood, CO.

resource. This step will create the base condition from which change will be measured. It will be important to accurately describe the productivity of the area and tie it to the vegetation condition. If the productivity is due to some factor other than the vegetation, this fact must be understood from the beginning because a change in the vegetation would not increase the productivity.

It is also important to identify those resources or uses that are not dependent on a particular vegetation condition so that they can be considered in subsequent steps. This would include such activities as oil and gas development, coal development, and float boating.

The next step in the process is to describe the desired vegetation condition and related productivity for each commodity resource or value of each non-commodity resource. It is likewise important to be able to accurately link the increase in productivity or value of the resource to the vegetation condition. If it is not known how productivity relates to the vegetation condition, then it is not possible to describe the desired vegetation condition to ensure that the productivity or value is realized.

The difference between the current vegetation condition and the related productivity or value and the desired vegetation condition and the related productivity or value can be considered the "opportunity for change" or "opportunity value." The objective of this planning process is to move from the current condition to the desired condition. The success of the plan can be measured in terms of the amount of the opportunity value that is being realized at any point in time.

The next stop is to determine if the planning area has the biological capability to achieve the desired vegetation condition and related productivity or value that has been previously identified. In many instances, some productivity or resource value may have to be adjusted or accommodated over time to be compatible with the biological capability of the planning area. When the planning area cannot produce all of the desired units or values, then the difference between desired productivity and potential productivity is considered to be a "planning issue" that needs to be addressed in the subsequent alternative discussion.

To summarize the planning process at this point, we have identified:

1. The current vegetation condition and related productivity;

2. The desired vegetation condition and related productivity;

3. The opportunity value;

4. The biological capability of the planning unit;

5. The difference between the desired condition and the biological capability.

The next step in the planning process is to identify what the minimum acceptable productivity or value will be for all resources or values. All minimum acceptable productivity or values must be achievable within the planning unit and must be able to be accommodated in each alternative that is developed. These minimums guarantee that a certain level of productivity or resource value will be realized no matter what alternative is finally selected.
The next step in the process is to develop alternatives to resolve the issues. Alternatives are the different ways to accomplish the same objective. All too often, land use plans confuse alternatives with options. Options are different objectives that can be met but they do not necessarily achieve the same objective. Alternatives in land use plans often use words such as "environmental alternative" or "commodity alternative" or "multiple use alternative" or some similar words. It sounds like each alternative is exclusive of each other. It appears that, if a commodity alternative is selected, sound environmental management will not occur. Or if an environmental alternative is selected, multiple-use management will not occur. Adversarial positions are developed among the various publics by the names that are given to the various alternatives.

Using alternatives in the proper sense does not require placing arbitrary names on each one. Since the objective is the same for each alternative, then none are "environmental" or "production" alternatives. The difference between alternatives is properly focused on the amount of opportunity value that is achieved. The vegetation condition and the relative productivity or value allows all interested publics to review a draft plan and comment on the various alternatives using the same basis. Comments can now be focused on the success of each alternative in achieving the opportunity value. Differences of opinion can be focused on something that can be addressed in re-analysis rather than differences relating to entirely different objectives. When there is no opportunity for change or if the planning area can completely accommodate the desired vegetation condition, productivity, or value, then there is no need to debate the issue unless there are opinions that affect the condition, production, or value.

A preferred alternative is selected that best meets the desired vegetation condition class and related productivity or value and meets the minimum acceptable levels identified for each resource.

The final step in the planning process is to select the final plan for the unit and begin implementation. An activity can be allowed within a particular area as long as the stated vegetation conditions can be realized and the productivity or value is achieved. If the proposal interferes with meeting the objective, then the proposal is rejected or a change in the stated vegetation condition is made through a plan amendment.

SUMMARY OF THE PLANNING STEPS

The ten steps in the planning system described above are:

1. Identify the current vegetation condition and related productivity.

2. Identify the desired vegetation condition and related productivity.

3. Determine the difference between the current and desired condition and related productivity (opportunity value).

4. Determine the biological capability of the planning unit.

5. Determine the opportunity for change in terms of either vegetation or productivity (desired minus current condition).

6. Where an area cannot achieve all of the desired vegetation conditions or productivity, a planning decision must be made (planning issue).

7. Criteria are developed to resolve the issue. These state what is the minimum acceptable condition.

8. Alternatives are developed to achieve the desired results, while meeting the minimum acceptable level for each resource.

9. A preferred alternative is selected that best meets the desired vegetation condition and related productivity and meets the minimum acceptable level for all resources.

10. A final decision is made and the plan is ready for implementation.

CONCLUSION

Land use plans developed using a vegetation condition approach would improve comparability and would serve the resource manager and public well in developing management objectives and in constructing a course of action that would guide changes in the vegetation condition from their current condition towards a desired condition.

VALUE OF "FIRE ECOLOGY OF WESTERN MONTANA FOREST HABITAT TYPES" TO RESOURCE MANAGERS

Anne F. Bradley

ABSTRACT: The publication "Fire Ecology of Western Montana Forest Habitat Types" presents generalized, multiple-pathway models of postfire succession for 11 "Fire Groups." Each fire group is composed of coniferous forest habitat types with a similar fire response. The groupings are intended to help managers understand how potential vegetation, fire severity, and stage of community development influence fire effects.

Classification based on potential vegetation can be used as a framework to summarize our current understanding of fire's natural role in forest succession. It can also help land managers determine whether fire is an appropriate tool to meet particular objectives. The recent publication "Fire Ecology of Western Montana Forest Habitat Types" (Fischer and Bradley 1987) is an application of classification to forest management. This document complements an earlier publication, "Fire Ecology of Montana Forest Habitat Types East of the Continental Divide" (Fischer and Clayton 1983).

In this fire ecology publication, habitat types are assigned to "Fire Groups" based on the response of dominant tree species to fire and the role these species take in forest succession. The description for each fire group includes information on forest fuels, the natural role of fire, plant community succession, and fire management considerations. Community succession is illustrated by multiple-pathway models (see fig. 1). These are modifications of earlier models describing how individual species' attributes affect the successional process (Kessell and Fischer 1981; Noble and Slatyer 1977, 1980). Information in the successional models synthesizes observed fire response and speculation based on dominant tree characteristics.

Fire groups provide generalized descriptions of fire behavior and plant response. Variation in fire behavior and successional patterns often depends on small local differences in fuel, moisture, topography, insolation, and tree seed availability. As a result, all stands in a habitat type may not fall into the same fire group. The individual land manager's assessment of site conditions is the final determinant in identifying the appropriate multiple-pathway model.

All Montana fire groups currently defined are listed below. Groups One and Three do not occur in western Montana. They are included to clarify the Fire Group numbering system.

Fire Group Zero: A heterogeneous collection of special habitats. In western Montana forests these sites exist as scree, forested rock, wet meadow, mountain grassland, aspen grove, and alder glade.

Fire Group One: Dry limber pine habitat types. These exist almost exclusively east of the Continental Divide in Montana.

Fire Group Two: Warm, dry ponderosa pine habitat types. This group consists of both open ponderosa pine stands with a predominantly grass undergrowth and dense mixed-age stands of ponderosa pine. These sites may exist as fire-maintained grasslands and do not support Douglas-fir except as "accidental" individuals.

Fire Group Three: Warm, moist ponderosa pine habitat types. These sites occur exclusively east of the Continental Divide in Montana; they are often occupied by stagnant, overgrown thickets of ponderosa pine saplings.

Fire Group Four: Warm, dry Douglas-fir habitat types. These sites support fire-maintained ponderosa pine stands under a natural fire regime. Where fire is suppressed, Douglas-fir regenerates beneath the pine and eventually dominates the overstory.

Fire Group Five: Cool, dry Douglas-fir habitat types. Douglas-fir is often the only conifer present on these sites. In the absence of fire, a dense Douglas-fir sapling understory may develop.

Fire Group Six: Moist, Douglas-fir habitat types. Douglas-fir often dominates all stages of succession on these sites, even when subjected to periodic fire.

Fire Group Seven: Cool habitat types usually dominated by lodgepole pine. This group includes stands where fire maintains lodgepole pine as the major seral species as well as those stands in which lodgepole is a climax dominant.

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Anne F. Bradley is a botanist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

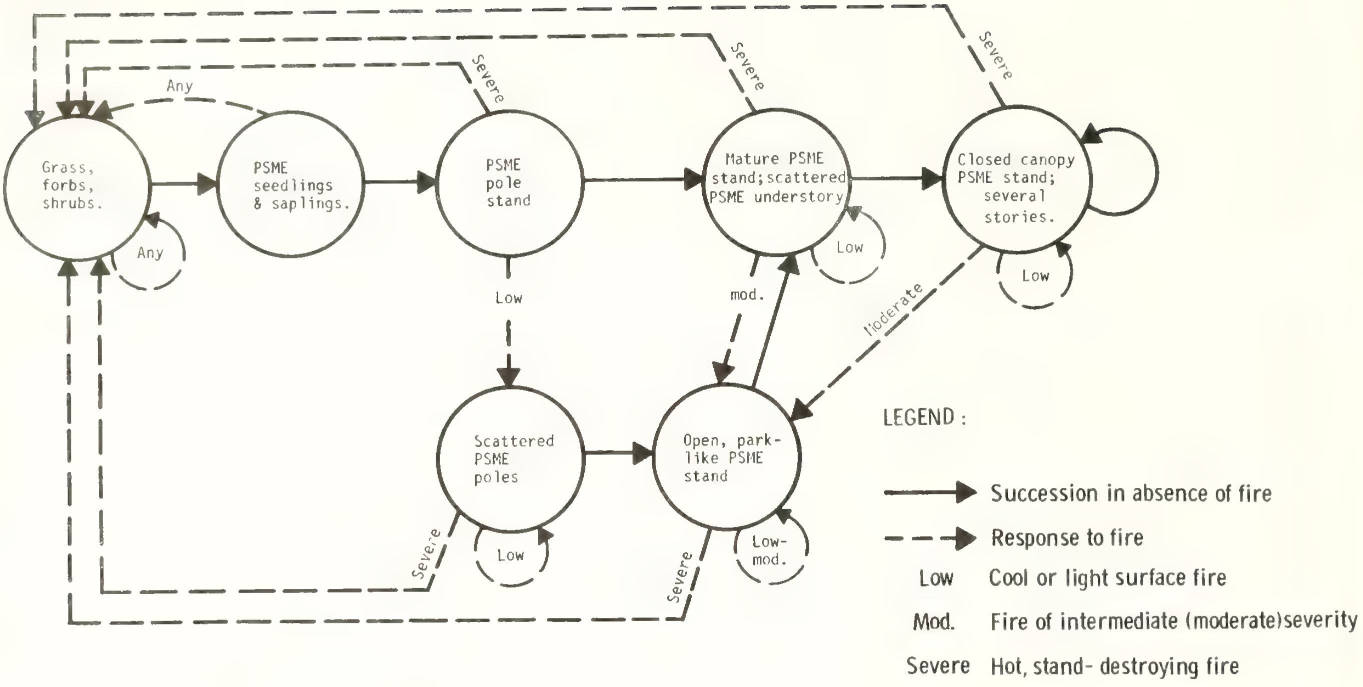
Grass, forbs, shrubs.
PSME seedlings & saplings.
PSME pole stand
Mature PSME stand; scattered PSME understory
Closed canopy PSME stand; several stories.
Scattered PSME poles
Open, park-like PSME stand
Any
Any
Severe
Severe
Severe
Low
mod.
Low
Low
Moderate
Low
Low-mod.
Severe
Severe
LEGEND :
Succession in absence of fire
Response to fire
Low Cool or light surface fire
Mod. Fire of intermediate (moderate) severity
Severe Hot, stand-destroying fire

Figure 1--Hypothetical successional pathways for Fire Group 5: cool, dry Douglas-fir habitat types.

Fire Group Eight: Dry, lower subalpine habitat types. This is a collection of habitat types in the spruce and subalpine fir series that usually supports mixed stands of Douglas-fir and lodgepole pine.

Fire Group Nine: Moist, lower subalpine habitat types. Fires are infrequent but severe in these types, and the effects of fire are long lasting. Spruce is usually a major component of seral stands.

Fire Group Ten: Cold, moist upper subalpine and timberline habitat types. These types occur in high-elevation habitats where fires are infrequent. Fires are often small in areal extent because of sparse fuels. Severe fires have long-term effects. Subalpine fir, spruce, whitebark pine, and subalpine larch are the dominant conifers.

Fire Group Eleven: Moist grand fir, western redcedar, and western hemlock habitat types. These habitat types are found on moist sites where fires are infrequent but often severe. In Montana, they occur exclusively west of the Continental Divide.

Once a land manager has linked a habitat or vegetation type to a fire group, its associated multiple-pathway model can be used to provide a basis for making broadscale predictions of the effects of fires of varying severities occurring at different stages of stand development. Managers can use these predictions to estimate potential plant response to fire, or to decipher some of the factors responsible for creating the current landscape.

REFERENCES

Fischer, William C.; Clayton, Bruce D. 1983. Fire ecology of Montana forest habitat types east of the Continental Divide. Gen. Tech. Rep. INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 83 p.

Fischer, William C.; Bradley, Anne F. 1987. Fire ecology of western Montana forest habitat types. Gen. Tech. Rep. INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 95 p.

Kessell, Stephen F.; Fischer, William C. 1981. Predicting postfire plant succession for fire management planning. Gen. Tech. Rep. INT-94. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Noble, I. R.; Slatyer, R. O. 1977. Post-fire succession of plants in Mediterranean ecosystems. In: Mooney, Harold A.; Conrad, C. Eugene, tech. coords. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems; 1977 August 1-5; Palo Alto, CA. Gen. Tech. Rep. WO-3. Washington, DC: U.S. Department of Agriculture, Forest Service: 27-36.

Noble, Ian R.; Slatyer, Ralph O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio. 43: 5-21.

STRATIFIED LANDSAT CLASSIFICATION OF NORTH-CENTRAL IDAHO AND ADJACENT MONTANA

Bart R. Butterfield, Dan L. Davis, and James W. Unsworth

ABSTRACT: In 1985 we began a stratified Landsat classification to classify and map vegetation on 3.5 million acres of land in north-central Idaho and adjacent Montana and provide a habitat data base to wildlife managers and researchers. Our objective is to classify and map vegetation in sufficient detail to serve as a data base for elk and grizzly bear habitat research. However, we realize that we are creating a highly detailed and generic classification that has many potential applications, wildlife being just one. The classification involves five steps: (1) topographic classification, (2) Landsat spectral classification, (3) collection of reference, or ground-truth, data, (4) stratification, and (5) incorporation of additional data layers. Defense Mapping Agency digital elevation data were used to create three topographic data planes: elevation, aspect, and slope. Landsat 5 MSS data were classified into 150 spectral classes using a guided clustering approach. Reference data have been collected for 1½ field seasons and, when completed, will be used to correlate the spectral classes with plant communities. We have been able to correlate some groups of spectral classes to general vegetation types with our existing reference data. The topographic and spectral data layers will be combined and used to split, or stratify, spectral classes that represent two or more vegetation types into distinct classes based on topographic modeling. Additional data planes can be used to stratify spectral classes based on features such as hydrology, snowchutes, geographic location, or any feature that can be mapped or modeled. Stratified Landsat classes that represent the same or similar plant communities will be pooled together to form working habitat classifications. Classes can be pooled in different combinations to produce different vegetation classifications for a wide variety of applications.

INTRODUCTION

Classifying and mapping vegetation on large expanses of remote, inaccessible land presents special difficulties. On-the-ground methods are limited by cost, time, and accessibility. Remote sensing provides greater coverage of the study area, but traditional aerial photograph interpretation suffers from lack of detail and variability in observer interpretation. Analysis of Landsat spectral data for applications in agriculture has proven successful and recent applications to wildland vegetation appear promising (Butterfield and Key 1986; Craighead and others 1982). Technological improvements in Landsat spectral data and analysis provide further promise in applications to wildland settings.

Faced with a need to classify and map wildlife habitat on 3.5 million acres of land, Clearwater National Forest, Nez Perce National Forest, and Idaho Department of Fish and Game joined in a cooperative effort to create a stratified Landsat classification of north-central Idaho and adjacent Montana in 1985. The primary author was contracted as an independent consultant to conduct the work. The major objectives are to classify, map, and evaluate grizzly bear habitat in the Bitterroot Mountains, and to classify and map elk habitat in the Clearwater Mountains. However, the actual process has been directed toward producing a detailed, but generic, vegetation classification which can be adapted to many different applications.

The study area consists primarily of the Bitterroot Mountains on the Idaho/Montana border and the Clearwater Mountains in Idaho. The entire area extends from north of Kelly Creek to just south of the Salmon River and from midway between Kooskia and Syringa, Idaho, to the Bitterroot Valley (fig. 1). Much of the study area is undeveloped, including the Selway-Bitterroot Wilderness Area, Gospel Hump Wilderness Area, and Frank Church-River of No Return Wilderness Area. Several other roadless areas are included as well as intensively managed areas on both the Clearwater and Nez Perce National Forests and adjacent National Forests.

Coniferous forests dominate the vegetation. North of the Lochsa River, western redcedar (Thuja plicata) and grand fir (Abies grandis) habitat types are prevalent. South of the Lochsa and Selway Rivers, these wetter types

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Bart R. Butterfield is a private consultant and owner of Mountain West Ecology, Moscow, ID; Dan L. Davis is Forest Wildlife Biologist, Clearwater National Forest, USDA Forest Service, Orofino, ID; James W. Unsworth is a Senior Wildlife Research Biologist, Idaho Department of Fish and Game, Lewiston, ID.

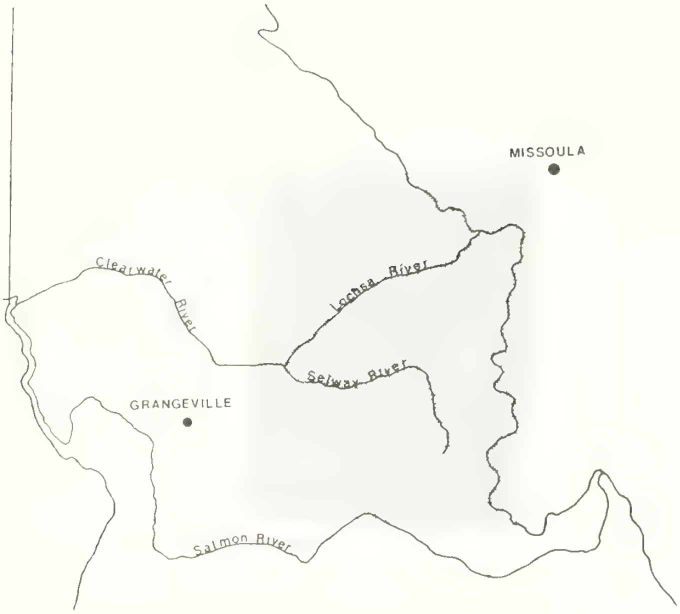


Figure 1--Location of the project area for the stratified Landsat classification of north-central Idaho and adjacent Montana.

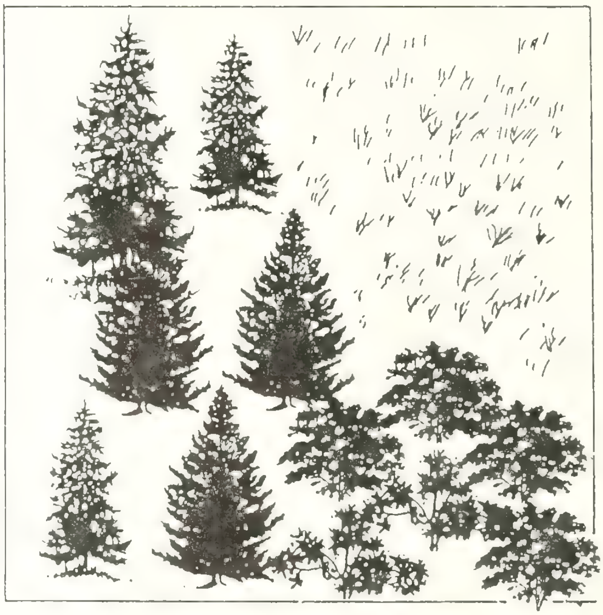
give way to drier Douglas-fir (Pseudotsuga menziesii) and ponderosa pine (Pinus ponderosa) habitat types. Subalpine fir (Abies lasiocarpa) habitat types occur above 5,000 to 6,000 feet elevation. Even-aged stands of lodgepole pine sometimes occur as fire regeneration, particularly south of the Selway River and in higher elevations to the north. Catastrophic fires in the early 1900's created large expanses of shrub fields north of the Selway and Lochsa Rivers, some of which even today lack conifer regeneration. Forb- and graminoid-dominated forest openings are patchy, but common. The forest cover is also broken by snow chutes in the Bitterroot Mountains. Although no true alpine vegetation occurs in the study area, an upper tree line exists in the Bitterroot Mountains due to the lack of soil and exposure of rock and its interaction with climate at higher elevations.

WHAT IS LANDSAT?

To fully understand the process and product, one must first understand Landsat and the concept of a digital image. Landsats are a series of satellites that circle the earth in circumpolar orbits. The satellites have several sensors on board that continuously measure and record the electromagnetic energy reflecting from the earth's surface. One of the sensors, the multispectral scanner (MSS) measures and records the earth's reflectance in four wavelength bands: green (0.5-0.6 μM), red (0.6-0.7 μM), infrared 1 (0.7-0.8 μM), and infrared 2 (0.8-1.1 μM).

The data are in the form of a digital image which can be envisioned as a huge grid over the earth's surface (fig. 2). For MSS data, the cell dimensions are sized to 50 by 50 m. Each cell of the grid contains numeric values representing the reflectance value from the earth in each of the wavelength bands. Any attribute of the earth's surface that can be represented by a number can be in the form of a digital image. In addition to the spectral data, we have elevation, aspect, and slope images in the stratified Landsat classification.

EARTH SURFACE



DIGITAL IMAGE

8	15	13	13	30	41	55	48	50	51
10	16	14	14	35	38	50	45	48	52
9	10	12	10	28	40	52	50	51	48
10	13	14	11	25	42	55	53	54	51
11	10	12	8	15	50	61	63	60	58
11	13	14	13	25	63	72	74	78	81
13	11	10	11	28	62	80	84	82	84
10	12	8	12	30	58	86	90	89	90
12	14	15	13	15	78	85	88	86	89
11	12	10	9	18	72	87	90	91	89

Figure 2--Depiction of a small section of the earth's surface and a corresponding digital image of the raw spectral data.

PROCEDURES AND PROGRESS

Producing the stratified Landsat classification image from the raw spectral data involves five major steps (fig. 3). (1) Using Defense Mapping Agency digital elevation data we created three topographic images: elevation in 40-foot increments, aspect in 5-degree increments, and slope in 1-degree increments. (2) We classified the raw Landsat spectral data into 150 spectral classes using a guided clustering approach (Hart and Wherry 1984). This approach allowed us some subjective control over the selection of clusters while still accounting for all the spectral and vegetative diversity in the study area. (3) Each spectral class must be directly correlated to vegetation on the ground. We are currently at this stage. We locate ground plots for each spectral class on a variety of elevations, aspects, and slopes. Vegetation is sampled using the Ecodata Method of the Forest Service, Northern Region. (4) Correlation of spectral classes to vegetation may indicate that some spectral classes represent more than one type of vegetation. For example, a meadow and a subalpine park may be classified as the same spectral class, because both are dominated by herbaceous and graminoid vegetation and have similar reflectance characteristics. They can be separated, or stratified, by combining the spectral and topographic classified images and modeling the topography of the two different types of vegetation (meadows have flat or low slopes, sidehill parks have steep slopes). (5) Additional data layers may be used to model certain vegetation types. For example, surface hydrology corridors can be used to model riparian vegetation and snow chutes may be modeled by geographic area and topography. Other data themes such as roads and trails may be useful for later analyses. The final product will contain many data layers.

The end product will be a highly detailed, yet generic, vegetation classification. We predict we will have over 200 stratified Landsat classes when we are finished. Of course, that is far too many classes for any practical application. Some stratified Landsat classes may be indistinguishable in terms of vegetation. The classification can be customized to fit most any application by pooling stratified Landsat classes to meet desired objectives.

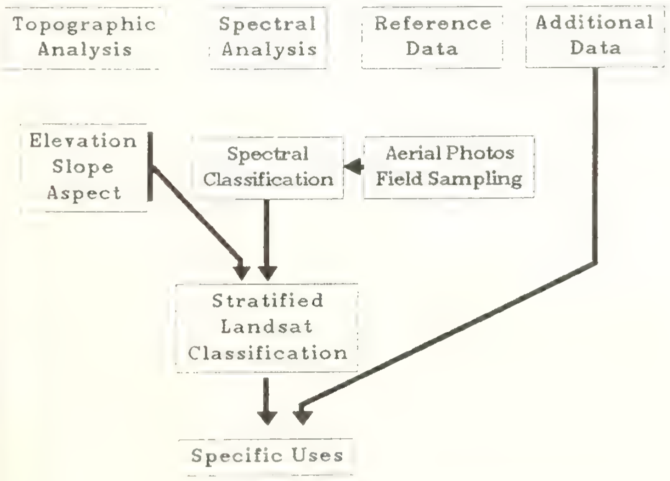


Figure 3--Flow chart of the stratified Landsat classification process.

APPLICATIONS

Grizzly Bear Habitat

The grizzly bear was classified as a threatened species in the conterminous 48 states in 1975 (USDI 1975). The official Grizzly Bear Recovery Plan (USDI 1982) identified the Bitterroot Mountains as one of six ecosystems for recovery of viable populations of grizzly bears. Little was known of the area including the population status of grizzly bears, the habitat value of the area, and even its political boundaries. The area has since been outlined and named The Bitterroot Evaluation Area (BEA).

The Recovery Plan prescribed two steps to be taken in the Bitterroot Mountains to assess the area's recovery potential: (1) determine the bear's population status and (2) evaluate the habitat for grizzly bear recovery. The presence of grizzly bears in the BEA is questionable, but unconfirmed reports are common (Melquist 1985). Scaggs (1979) and Butterfield and Almack (1985) have conducted cursory surveys of grizzly bear habitat in the Selway-Bitterroot Wilderness Area. The present study is a comprehensive inventory and evaluation of the entire BEA using a stratified Landsat classification.

Butterfield and Key (1986) demonstrated that stratified Landsat classifications can be effectively applied to grizzly bear habitat mapping. Our stratified Landsat classes will be grouped into vegetation types that best describe grizzly bear habitat components. Additional data layers will be needed to model snow chutes, fire regeneration, riparian corridors, and other habitat components used by grizzly bears.

Grizzly bear habitat models being developed by the Forest Service, Northern Region, will be applied to the digital grizzly bear habitat classification to evaluate habitat in the BEA. The models will extrapolate from grizzly bear habitat-use and food-habits data collected in other ecosystems that have viable grizzly bear populations.

Elk Habitat Use

Idaho Department of Fish and Game personnel are collecting radio-location data on elk in the Clearwater and Lochsa River drainages as part of a study to examine habitat use by elk. Because the stratified Landsat classification is georeferenced to the Universal Transverse Mercator grid system, the radio-locations or home range calculations can be directly input into the stratified Landsat classification digital image. A variety of analyses can then be performed by computer to examine habitat use. Stratified Landsat classes will be combined in the same manner the grizzly bear habitat classes were, but in combinations to meet the elk research and management objectives.

Other Applications

The stratified Landsat classification will be a very detailed breakdown of vegetation. The 150 spectral classes will result in approximately 200 stratified classes. Each stratified class will be correlated to some combination of plant species composition and abundance. Other data being collected for correlation include fuel classes, successional status, habitat type, ground cover, and basal area. With this data and the ability to combine the stratified Landsat classes in any combination desired, classifications for a variety of applications are possible. For example, stratified Landsat classifications may be useful for fire behavior modeling, habitat type mapping, and forest planning. Other data can be added in the future for other unforeseen applications.

REFERENCES

Butterfield, Bart R.; Almack, Jon A. 1985. Evaluation of grizzly bear habitat in the Selway-Bitterroot Wilderness Area. Boise, ID: Idaho Department of Fish and Game. 64 p.

Butterfield, Bart R.; Key, Carl H. 1986. Mapping grizzly bear habitat in Glacier National Park using a stratified Landsat classification: a pilot study. In: Proceedings - grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 58-66.

Craighead, John J.; Sumner, J. S.; Scaggs, G. B. 1982. A definitive system for analysis of grizzly bear habitat and other wilderness resources. Wildlife-Wildlands Institute Monograph 1. Missoula, MT: University of Montana. 279 p.

Hart, Judy A.; Wherry, David B., eds. 1984. VICAR/IBIS user reference manual. Pullman, WA: Graphics and Image Analysis Group, Computing Service Center, Washington State University. 4 vol.

Melquist, Wayne E. 1985. A preliminary survey to determine the status of grizzly bears in the Clearwater National Forest of Idaho. Moscow, ID: University of Idaho, Forest, Wildlife, and Range Experiment Station. 50 p.

Scaggs, Gordon B. 1979. Vegetation description of potential grizzly bear habitat in the Selway-Bitterroot Wilderness Area, Montana and Idaho. Missoula, MT: University of Montana. 148 p. Thesis.

U.S. Department of Interior. 1975. Amendments to the regulations for endangered and threatened wildlife. Washington, DC: Federal Register. 40: 44412.

U.S. Department of Interior. 1982. Grizzly bear recovery plan. Washington, DC: U.S. Department of Interior, Fish and Wildlife Service. 195 p.

INTEGRATED INVENTORY--BRIDGER-TETON NATIONAL FOREST

T. M. Collins, M. Blackwell, J. Nordin, and A. P. Youngblood

ABSTRACT: Resource inventories have been integrated for a portion of the Teton National Forest and recorded on the same photographic base. This approach provides different combinations of information for managers. Information in this form may increase efficiency and effectiveness of resource manipulations such as prescribed burning, reforestation, wildlife improvement projects, and timber harvest.

INTRODUCTION

Interpretations based solely on single-resource inventories often have limited ability to predict various responses to management actions, especially the response of vegetation. Vegetation is often dynamic, with management options varying depending upon successional stage and past disturbance. Any given site, however, may support only one particular plant community at climax. This potential community is the result of integration of all environmental factors affecting the vegetation, including parent material, soil development, climate, fauna, and time. Similar sites or units of land that potentially support the same climax vegetation (habitat types) are useful for relating successional trends and communities, productivities, and responses to surface manipulations. Soil resource surveys, in contrast, provide little interpretive potential for projecting successional trends, productivities of seral communities, or responses of vegetation to prescribed fire or timber harvesting. Conversely, soil surveys provide data useful for considering road building alternatives while habitat type classifications may be of limited benefit.

This paper addresses an integrated inventory approach implemented on the Bridger-Teton National Forest in western Wyoming. Objectives were (a) to test the potential application of integrating soil resource survey, habitat type, and geologic hazard mapping across a large unit of land; (b) to provide essential information needed by management, in a suitable format, with the appropriate specificity; (c) to provide interpretations for various resource manipulations and management goals; and (d) to increase the utility and effectiveness of the inventory data by presenting them in a way that allows a variety of data combinations.

INTEGRATED INVENTORY METHODS

In 1980, a progressive soil resource survey of the Teton National Forest (now administered as part of the Bridger-Teton National Forest) was formally initiated. This Order III soil survey delineated contrasting soils to a minimum size of 40 acres. Map units were composed primarily of complexes and associations with soils classified at the family level (USDA 1975). The soil resource inventory was correlated to meet all USDA standards. At the same time, geologic hazard mapping was conducted for the survey area. Areas of mass movement, including active and stable landslides and rockfall, were mapped following established USDA Forest Service, Intermountain Region, guidelines (DeGraff and others 1979). Geology hazard mapping was conducted on a variety of air photo scales, but was later transferred to the soil inventory photo base.

Mapping of habitat types began in 1979 using map scales similar to the soil photo base. Habitat type maps delineated units of land with associations of habitat types and stable community types. Where habitat type maps were not available, extrapolation from adjacent areas, site data from project work, and observations made during the soil mapping were used.

Pairs of orthoquad mylars, consisting of the respective soil map and habitat type delineations, were superimposed and the occurrence of soil and habitat type delineations with correspondence were noted. Where delineation boundaries were similar, the occurrence was recorded. Units with repeated correspondence across a geographic distribution (throughout a single quad or on several quads) were reviewed for common conceptual features such as slope, aspect, topography, elevation, exposed rock, and existing seral vegetation.

Poster paper presented at the Symposium on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

T. M. Collins is Regional Soil Scientist, Forest Service, U.S. Department of Agriculture, Intermountain Region, Ogden, UT; M. Blackwell is Soil Scientist, Forest Service, U.S. Department of Agriculture, Wasatch National Forest, Salt Lake City, UT; J. Nordin is Soils Specialist, U.S. Department of Agriculture, Forest Service, Washington Office; A. P. Youngblood is Research Forester, Forest Service, U.S. Department of Agriculture, Pacific Northwest Research Station, Fairbanks, AK.

A listing of each soil map unit and its corresponding habitat type units summarized the map overlay correlation. Computer-assisted sorting identified soil map units and habitat type units with high correspondence, indicating repeated common delineations (Youngblood 1984). The conceptual basis for each pair was reviewed to isolate common features such as topographic position and geographic distribution. Similar soil map units with similar habitat type units were combined to form habitat type groups. Where appropriate, the groups were disaggregated based on slope or moisture criteria that may further refine and influence management options (for example, Groups 2D and 5A in tables 1 and 2).

Table 1--Example of range management interpretation from an integrated inventory, Bridger-Teton National Forest

Soil map unit	Erosion hazard	Revegetation limitation	Range productivity	Habitat type group[1]	Stability rating
110 (0-5% slopes) Alluvial terraces				2D	STABLE
SOIL 1 (30%)	LOW	SEVERE: STONES	LOW		
SOIL 2 (30%)	LOW	SEVERE: STONES	MODERATE		
SOIL 3 (30%)	LOW	SEVERE: STONES DROUGHTY	LOW		
202 (10-30% slopes) Rolling mtn. slopes				5A	M-STABLE
SOIL 1 (65%)	MODERATE: ERODES EASILY	MODERATE: SLOPE	HIGH		
SOIL 2 (25%)	HIGH: SLOW INTAKE PERCS SLOWLY	MODERATE: CLAYEY	HIGH		
459 (30-60% slopes) Benchy sideslopes				4	UNSTABLE
SOIL 1 (30%)	HIGH: PERCS SLOWLY SLOPE	MODERATE/SEVERE: SLOPE/ SLOPES <40%	HIGH		
SOIL 2 (25%)	HIGH: SLOPE EXCESS FINES	SEVERE/VERY SEVERE: SLOPE/ SLOPES <40%	MODERATE		
SOIL 3 (25%)	HIGH: SLOPE	SEVERE/VERY SEVERE: DROUGHTY/ SLOPES <40%	LOW		
616 (10-30% slopes) Foothills and basins				7	M-STABLE
SOIL 1 (50%)	HIGH: SLOW INTAKE PERCS SLOWLY	SEVERE: TOO CLAYEY SLOW INTAKE	MODERATELY LOW		
SOIL 2 (25%)	HIGH SLOW INTAKE PERCS SLOWLY	SEVERE: TOO CLAYEY SLOW INTAKE	HIGH		
646 (10-40% slopes) Hummocky earthflows				5A	M-UNSTABLE
SOIL 1 (60%)	MODERATE/HIGH: PERCS SLOWLY SLOPES <30%	MODERATE/SEVERE: SLOPES SLOPES <25%	HIGH		
SOIL 2 (25%)	HIGH: ERODES EASILY PERCS SLOWLY	MODERATE/SEVERE: TOO CLAYEY SLOPES <25%	HIGH		

[1] See table 2 for explanation.

Table 2--Soil map unit-habitat type correlations from integrated inventory, Bridger-Teton National Forest

Habitat type group	Soil map unit	Habitat types	Other significant vegetation
2D	101 and 110	ARAR/AGSP ARLO/AGSP ARTRV/STCO	*Agropyron dasystachyum* *Agropyron smithii* *Stipa occidentalis* *Poa sandbergii*
4	340, 342, 456, 459	ARTRV/SYOR-AGSP ARTRV/SYOR-FEID ARTRV/STCO WYAM c.t. AGUR-VIMU c.t. BASA-HEUN c.t.	*Chrysothamnus viscidiflorus* *Prunus virginiana* *Berberis repens* *Eriogonum umbellatum* *Leucopoa kingii* *Crepis acuminata*
5A	202, 376, 646	ARTRV/FEID-GETR ARCA/FEID ARLO/FEID WYAM c.t. BASA-HEUM c.t.	*Bromus anomalus* *Stipa occidentalis* *Artemisia tripartita*
7	616	ARLO/FEID ARCA/FEID WYAM c.t.	*Wyethia amplexicaulis* *Potentilla fruticosa*

The soil map units within a habitat type group may have some similar responses to management if habitat types that comprise the group have similar responses. Table 2 lists the habitat type groups with their soil map units, the representative associated habitat and community types, and significant associated vegetation. Narrative descriptions of each habitat group were included in the final inventory report (Nordin and Blackwell 1987).

In this survey, the soil map unit or the component of the map unit became the integrating factor. The habitat type was considered in soil map unit design, but was used primarily to characterize the soil map unit. Active geologic hazards wre mapped independently by geomorphologists. Geologic hazard potentials, however, were considered in map unit design. Active geologic hazards were included on the final maps.

APPLICATIONS AND MANAGEMENT

Utilization of integrated inventory information in management decisions and project activities is key in the acceptance of the inventory. Formulation of the inventory through an interdisciplinary approach may lead to more widespread use. Two examples will illustrate typical application of the data by resource managers.

Blue grouse, a native upland bird common to the northern Rocky Mountains, resides year round by adjusting its habitat by season and activity. Wildlife management goals often include objectives for improving habitat and increasing distribution across potentially suitable land areas. Generally, these areas contain within close proximity a food source, such as pine and spruce seeds produced in old-growth, open conifer stands, hiding cover during brooding periods, such as open mountain slopes dominated by sagebrush and tall forbs, and a water source. These characteristics occur in part on Soil Map Units 342 and 456, which occupy south-facing slopes. The soils are generally shallow to moderately deep. Slopes are generally steeper than 50 percent, with numerous rock outcrops. Table 2 lists the habitat types in Group 4 that are generally associated with these soil map units. Wildlife managers may quickly recognize specific sites meeting the species habitat requirements, and identify acreages and locations suitable for wildlife habitat improvement projects. Alternatives for treatment and management practices could be derived from a combination of vegetative structure information based on plant succession and potential response of soils based on productivity and hazards.

Livestock grazing represents a major dispersed use of National Forest System lands. Efforts to reduce grazing impact and increase available forage are key management concerns. Increasing available forage often involves reduction of sagebrush cover by prescribed burning. Variables contributing to success include site productivity, erosion hazard, existing species composition, and the potential natural community (habitat type). Site productivity and erosion hazard may be a function of soil moisture holding capacity, depth to bedrock, texture, rock fragment content, aspect, slope, and position on slope; these features are used to develop soil map units. Site productivity, existing species composition, and the potential natural community type are often derived from habitat type classifications. In western Wyoming, several species of sagebrush are often found on the same site. Mountain big sagebrush (Artemisia tridentata ssp. vaseyana) is easily killed by fire, while silver sagebrush (Artemisia cana) resprouts vigorously following burning. Habitat types supporting mountain big sagebrush but not silver sagebrush on soils with high productivity and low erosion hazard are identified as suitable for treatment by prescribed fire.

Tables 1 and 2 are examples of the kind of interpretative data that appear in the final report. Soil map units in table 1 have stability ratings and are linked to habitat type groups. Detailed habitat type and plant species information are presented in table 2, and cross-linked to various soil map units. Cross-linking provides various combinations of information for the user. For example, some soils in Map Unit 202 have characteristics desirable for prescribed burning for range improvement, such as moderate erosion hazard and high range productivity. Table 2 indicates, however, that Habitat Type Group 5A, which occurs on Soil Map Unit 202, may support silver sagebrush. Thus, the habitat type indicates a potentially limiting factor even though soil characteristics suggest the appropriateness of using prescribed fire for range improvement. In contrast, Habitat Type Group 4 indicates the presence of mountain big sagebrush and a good opportunity for range improvement. Soils in Map Unit 459, however, are highly erosive and unstable.

Interpretations traditionally based on physical soil properties are enhanced by knowledge of plant succession, geologic hazards, and revegetation potentials. Stratification of habitat types by specific soil properties enables application in areas where drastic ground disturbances are anticipated. Not all integrated inventories will require the same components. Because the portion of the Teton National Forest surveyed for this inventory contained landscapes with a high rate of mass movement, geologic hazard was selected as a component. This component need not be considered for areas with low rates of mass movement.

Unit costs for this integrated inventory were higher than traditional soil inventories, but were substantially lower than the cost of conducting the inventories separately.

SUMMARY

Complex landscapes and resource values suggested the need for an integrated inventory approach to resource survey on a portion of the Teton National Forest in western Wyoming. Topography, landform, habitat type, and geologic hazards, in addition to traditional soil survey data, were considered essential for providing resource management interpretations. The soil resource inventory was the mapping core of the integrated inventory, providing a mechanism for storage and a method for relating other resource information to uniform, repeatable land delineations. The nationally standardized mapping procedures, correlation, and quality control of the National Cooperative Soil Survey ensured consistency and increased utility of all resource data. This approach allowed a variety of resource information to be collected at one time for the same land area and recorded on the same photographic base. Managers may use several combinations of information provided by the integrated inventory in making decisions and increasing efficiency and effectiveness of resource manipulations such as prescribed burning, reforestation, wildlife improvement projects, and timber harvest.

While no detailed economic studies have been completed, we believe there are substantial dollar and time savings by using the integrated approach rather than the traditional individual resource inventory approach. User satisfaction is high and peripheral resource information is enhanced. Future use of the integrated information will likely be compatible with a variety of geographic information systems.

REFERENCES

DeGraff, J. V.; Olson, E. P.; Collins, T. M.; Godfrey, A. 1979. Inventory of geological hazards. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 29 p.

Nordin, J.; Blackwell, M. 1987. Soil survey of the Teton National Forest, parts of Teton, Fremont, Park, Sublette, and Lincoln Counties, WY. Unpublished draft on file at: U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT. 348 p.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy. Agric. Handb. 436. Washington, DC. 754 p.

Youngblood, A. P. 1984. Unpublished data on file at: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Fairbanks, AK.

AN EXAMPLE OF BIOPHYSICAL HABITAT MAPPING IN BRITISH COLUMBIA

Dennis A. Demarchi and E.C. (Ted) Lea

ABSTRACT: Information collected on site, soil, vegetation and wildlife and mapped at a scale of 1:20 000 is used to define management options for improving the habitat of selected wildlife species in the Sheep Mountain wildlife area in southeastern British Columbia. An example of one biophysical habitat unit is described and management options are provided.

INTRODUCTION

The Sheep Mountain wildlife area is located in the southern portion of the Rocky Mountain Trench; south of Elko, between Highway 93 and the Elk River. In 1962 the B.C. Fish and Game Department purchased 64.8 ha at the base of Sheep Mountain and in 1985, a consortium of conservation groups (Wildlife Habitat Canada, Nature Trust, Kootenay Wildlife Heritage Fund and the Habitat Conservation Fund) purchased 364.2 ha that was owned by Jack Cutts.

Objectives

The policies and objectives that will guide the management and protection activities on the Sheep Mountain wildlife area are based, in part, on ecological information provided by a Biophysical Habitat inventory. The objectives of the biophysical inventory were to provide: an ecological framework for assessing the habitats used by big game animals during critical seasons of the year (in this case winter) and habitats used by other wildlife species; and for planning habitat enhancement activities (Lea and others 1987).

Wildlife

The Sheep Mountain wildlife area provides important winter habitat for a variety of big game animals, most numerous are elk and white-tailed deer, but, historically mule deer were abundant in periods of early successional stages. Bighorn sheep and moose also inhabit this winter range but their numbers are small, as the amount of habitat that could support these species is limited. Other animal species on the Sheep Mountain wildlife area that are of management concern are: badgers, red-tailed hawks, golden eagles, and Columbian ground-squirrels.

Terrain Soils

The landscape of the Sheep Mountain area was shaped by glacial activity which occurred from 17,000 to 11,000 years ago, although downcutting of rivers occurred since then (Ryder 1981). Much of the area consists of materials that were deposited beneath 1,500-m-thick ice, called glacial till; or materials formed or deposited by flowing water surrounding or in front of the glacier, which are called fluvioglacial materials (Lacelle 1987).

Vegetation

The area, as was most of the Trench from the Tobacco Plains and Newgate areas north to Dutch Creek, was burned by two large fires in July, 1931. The resulting habitats were largely shrub/grass dominated. Since that time conifer trees have become reestablished over much of Sheep Mountain and the Trench (Lea 1984).

At present the vegetation of the Sheep Mountain area is characterized as having a mosaic of closed forests, open forests, shrub/grasslands and abandoned fields. The closed forests are dominated by Douglas-fir and ponderosa pine with a pinegrass understory. Open forests have Douglas-fir and ponderosa pine with an understory of antelopebrush, bluebunch wheatgrass, Idaho fescue and Junegrass. Shrub/grassland communities are seral to forests and are composed of antelopebrush, bluebunch wheatgrass, Idaho fescue, kinnikinnick and Junegrass.

AN EXAMPLE OF A SPECIFIC HABITAT UNIT

Douglas-fir - Antelopebrush Fluvial Habitat

This habitat unit is characterized by: level to gently rolling, fluvial plains that extend to the edge of the terrace face above the Elk River (See table 1 and fig. 1). Management of this habitat unit should consist of maintaining the existing openings by prescribed burning in 15-20 year intervals, except Douglas-fir should be planted around the perimeter of the cultivated fields at the Cutt's ranchstead. Cover that surrounds the open habitat should be maintained to provide visual barriers, temporary shelter and protect travel corridors for elk and white-tailed deer (See table 2 and fig. 2).

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Dennis A. Demarchi is Habitat Classification Specialist; E.C. (Ted) Lea is Plant Ecologist; both are with Wildlife Branch, British Columbia Ministry of Environment and Parks, Victoria, B.C. Canada.

Table 1--DAf Douglas-fir - antelopebrush fluvial habitat unit (see fig. 1)

Description: Level to gently-sloped areas of terraces or plains with a sand to silt textured veneer of fluvial or aeolian (windblown) materials over a gravelly subsoil. Widespread unit in study area; slow rate of succession particularly in early stages which are quite droughty; slow establishment of trees; understory vegetation is more related to canopy cover than age of stand; hot burns in summer or fall will kill most of the antelopebrush; may be more potential for rough fescue than noted, as it appears to be heavily used; bluebunch wheatgrass and fescues are susceptible to overgrazing.

Map Symbol	Vegetation			
	Successional Trends		Ungulate Forage	
	Dominants	Associates	Abundant (>20% cover)	Moderate (5-20% cover)
DAF1*	shrub-grassland of: antelopebrush bluebunch wheatgrass Idaho fescue kinnikinnick Junegrass	saskatoon rose spreading needlegrass rough fescue Kentucky bluegrass orange arnica wild bergamot	antelopebrush bluebunch wheatgrass Idaho fescue	saskatoon rose kinnikinnick needle grasses rough fescue Kentucky bluegrass Junegrass pasture sage Hood's phlox
DAf2 DAf4 DAf6	parkland to open forests of: Douglas-fir ponderosa pine antelopebrush bluebunch wheatgrass Idaho fescue	saskatoon choke cherry rough fescue Junegrass pinegrass	Douglas-fir antelopebrush Idaho fescue	saskatoon choke cherry rose rough fescue needle grasses kinnikinnick Hood's phlox
DAf3 DAf5 DAf7	closed forests of: Douglas-fir pine grass	ponderosa pine snowberry birch-leaved spirea Oregon-grape rough fescue heart-leaved arnica	Douglas-fir	snowberry Oregon-grape mallow ninebark rough fescue bluebunch wheatgrass

*Successional Stages
1. Recent disturbance.
2. Young (less than 40 years), moderate forest canopy (25 to 65% cover).
3. Young (less than 40 years), dense forest canopy (greater than 65% cover).
4. Mature (40-120 years), moderate forest canopy (25 to 65% cover).
5. Mature (40-120 years), dense forest canopy (greater than 65% cover).
6. Old growth (greater than 120 years), moderate forest canopy (25 to 65% cover).
7. Old growth (greater than 120 years), dense forest canopy (greater than 65% cover).

REFERENCES

Demarchi, D.A. 1986. Biophysical resources of the East Kootenay area: Wildlife. Ministry of Environment and Parks Technical Report 22. British Columbia Ministry of Environment and Parks, Wildlife Branch, Victoria, B.C. 134 p.

Lacelle, L.E.H. 1987. Biophysical resources of the East Kootenay area: Soils. British Columbia Ministry of Environment and Parks, Wildlife Branch, Penticton, B.C. 200p. Editorial draft.

Lea, E.C. 1984. Biophysical resources of the East Kootenay area: vegetation. Volume 1, Ministry of Environment Technical Report 5. British Columbia Ministry of Environment, Surveys and Resource Mapping Branch, Victoria, B.C. 75p.

Lea, E.C.; Demarchi, D.A.; Lacelle, L.E.H. 1987. Biophysical analysis of the Sheep Mountain wildlife area. Wildlife Branch, British Columbia Ministry of Environment and Parks, Victoria, B.C. 87p. Editorial draft.

Ryder, J.M. 1981. Biophysical resources of the East Kootenay area: terrain. APD Bulletin 7. British Columbia Ministry of Environment, Terrestrial Studies Branch, Victoria, B.C. 152p.

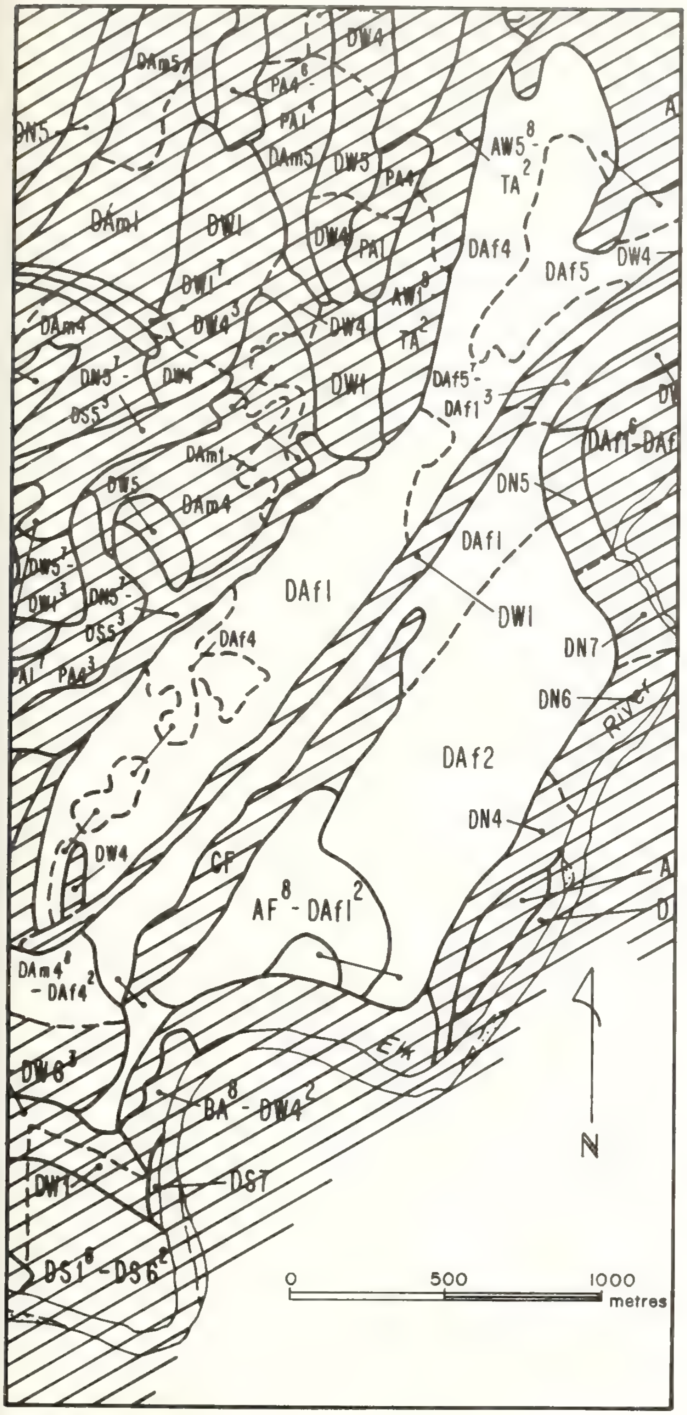

Figure 1--The location of the Douglas-fir - antelopebrush fluvial habitat unit and the distribution of the various successional stages within the habitat unit (see table 1).

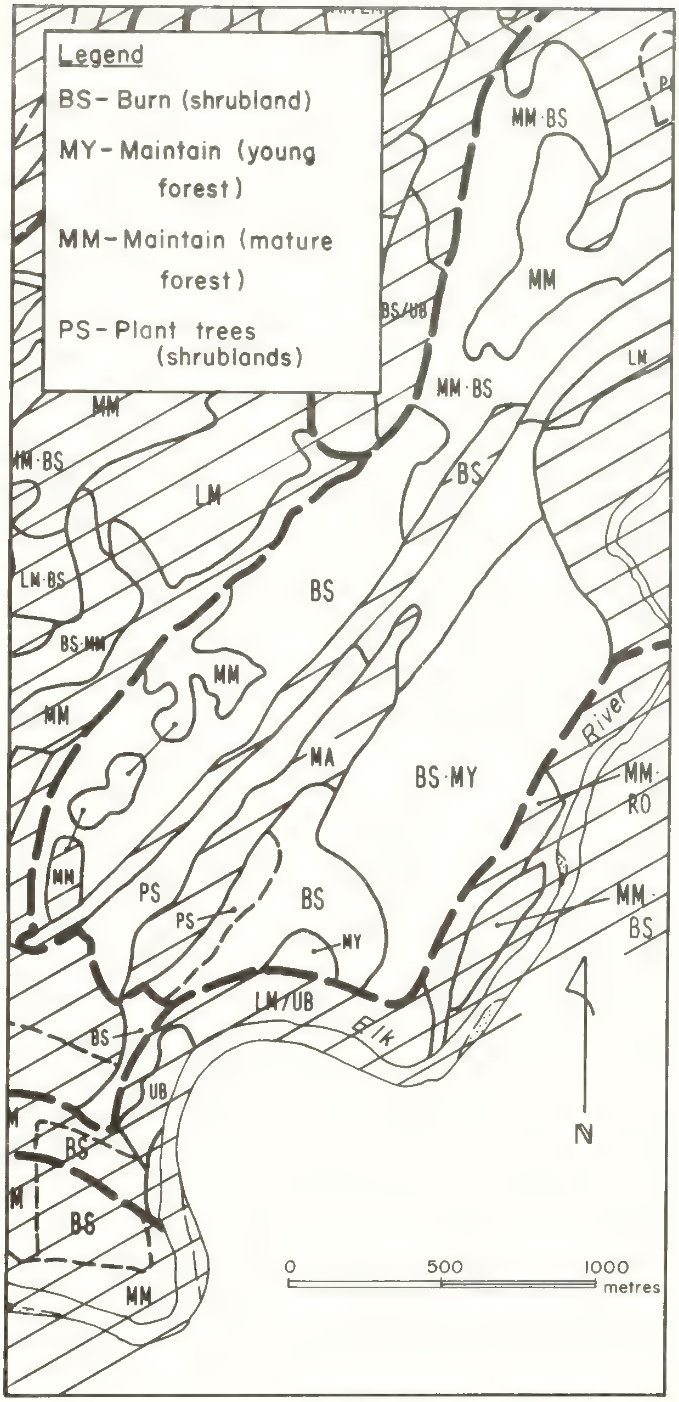

Figure 2--The recommended management prescriptions of the various successional stages of the Douglas-fir - antelopebrush fluvial habitat units (see table 2).

Table 2--Type of ungulate winter use and limitations, habitat manipulation considerations and treatment recommendations for the DAf Douglas-fir - antelopebrush fluvial Biophysical Habitat Units within Treatment Unit Three (see fig. 2)

Existing Successional Stages-Size and Number of Units	DAf 1 early succession (logged or heavily grazed) 103 ha/6		DAf 2 young trees (less than 40 years), moderate forest canopy (25-65% cover) 72 ha/2		DAf 4 mature trees (40-120 years), moderate forest canopy (25-65% cover) 61 ha/6		DAf 5 mature trees (40-120 years), dense forest canopy (greater than 65% cover) 38 ha/3	
Present Winter Use suitability for:	Forage	Cover	Forage	Cover	Forage	Cover	Forage	Cover
Elk	high-mod.	nil	high	high	mod.-high	high	mod.	high
White-tailed Deer	high-mod.	nil	high	high	mod.-high	high	high	high
Mule Deer	mod.	nil	mod.	high	mod.-high	high	low	high
Bighorn Sheep	high	nil	mod.	mod.	low	low	low	low
Limitations for present ungulate use	-little cover -heavily grazed -too flat for mule deer & bighorn sheep -only areas adjacent to escape terrain good for mule deer and bighorn sheep		-low snow interception -too flat for mule deer -adjacent escape too forested for bighorn sheep		-heavily grazed -too far from escape for bighorn sheep (except 2 units)		-canopy too dense for abundant forage -portion of large unit too far from escape terrain for bighorn sheep	
Habitat Manipulation Considerations	-droughty, coarse soils -wind erosion may occur after disturbance -nutrient depletion may occur due to volatilization and leaching following burning -slow rate of succession -antelopebrush is killed by hot fires		-same as DAf 1 -canopy well spaced and clumped, excellent hiding cover		-same as DAf 1 -on the terrace these units often provide the first hiding cover from more open units -on the terrace face these units are only two of many forested units		-same as DAf 1 -these units are located between the most open units and the forested terrace face -these units are important as travel routes and hiding cover for all but bighorn sheep	
Habitat Treatment Recommendations for: Elk	-prescribed burn in fifteen year cycles*; stagger the burning so not every unit is burned in the same year*; reduce cattle grazing*; in the largest units plant Douglas-fir in center to provide hiding cover*		-patch burn some of the unit in 15 year cycles to maintain opening* (some canopy can be eliminated but most is an asset); reduce cattle grazing*; one pass Christmas tree cutting*		-patch burn some of each unit in 15 year cycles to maintain openings and rejuvenate antelopebrush* (most of the canopy is an asset); reduce cattle grazing*; leave some canopy on all units*		-maintain canopy in all units*	
White-tailed Deer	-as above		-as above		-as above		-as above	
Mule Deer	-as above		-as above		-as above		-as above	
Bighorn Sheep	-as above		-maintain largest openings nearest edge of terrace*		-manipulation of forest along terrace edge is in conflict with elk and white-tailed deer management		-management not applicable except for northern-most unit, between terrace edge and AF unit; excellent forage for bighorn sheep if completely cleared (management is in conflict with elk and white-tailed deer management)	

*Recommended priority management activity for the specified successional stage.

BIOPHYSICAL HABITAT CLASSIFICATION IN BRITISH COLUMBIA:
AN INTERDISCIPLINARY APPROACH TO ECOSYSTEM EVALUATION

Dennis A. Demarchi and E.C. (Ted) Lea

ABSTRACT: The British Columbia Ministry of Environment and Parks has developed and implemented a multi-disciplinary, multi-scale habitat classification for wildlife and habitat planning and management purposes.

INTRODUCTION

Ecological classification and mapping done by the Wildlife Branch of the British Columbia Ministry of Environment and Parks is oriented toward identifying habitat for selected animal species, such as ungulates and bears. The emphasis on other animals is developing as requests for this information increase. The two main goals of biophysical mapping are (1) to provide a framework to assess the suitability and capability of the land surface for supporting wild animals (Demarchi and others 1983; Fuhr 1987) and (2) to provide a framework for improving animal habitat. The biophysical classification describes and maps land areas that have relatively homogeneous climatic, physical (including soil) and vegetative characteristics of importance to animals.

The hierarchy used for biophysical mapping includes Ecoregions, Biogeoclimatic Units (zonation) and Biophysical Habitat Units (table 1). Ecoregions are broad ecological units for the province, based on climatic processes, physiography, and broad animal and plant distribution (Demarchi 1987). Biogeoclimatic Units, as mapped by the British Columbia Ministry of Forests and Lands, provide a climatic framework for mapping within each Ecoregion, as well as a framework for mapping plant community distribution (Pojar and others 1986). In mapping, we usually use Biogeoclimatic Subzones. Biophysical Habitat Units, the lowest level of our mapping hierarchy, are relatively homogeneous units with respect to soils, surficial material, bedrock geology, climate, topography, successional trends of vegetation and potential animal use (Demarchi and others 1988) (fig. 1). These units are divided into successional stages for mapping. Predictability of vegetation parameters is important to determine what areas can be improved for forage and cover for animals. We describe the vegetation, and potential forage and cover characteristics for animals, for all successional stages. Most of our interpretations for animals are done from these units. Our maps are presented at various scales, with 1:50,000 and 1:20,000 scales being most common.

In our classification and mapping, there is a strong emphasis on physical attributes, and successional as well as climax vegetation, as potential animal habitat use is strongly reflected by these features.

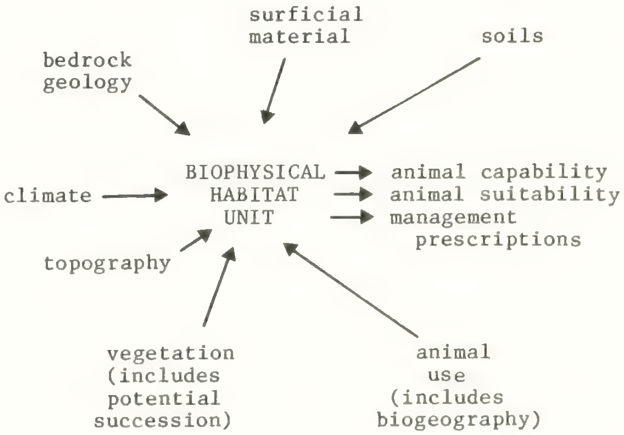

Figure 1--Parameters used to define Biophysical Habitat Units.

Field crews usually consist of a pedologist, who interprets bedrock geology, surficial materials and soils; a vegetation ecologist who interprets climatic parameters, succession and stand characteristics; a biologist who interprets current animal use and potential occurrence. All are responsible for developing habitat management interpretations. Our greatest successes began when scientists from all three disciplines were present during field trips, agreed to the location of each plot and then simultaneously sampled the site. Interpretations and unit delineation were also best served when the same air photos were used.

Poster presented at the Symposium on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Dennis A. Demarchi is Habitat Classification Specialist; E.C. (Ted) Lea is Plant Ecologist; both are with Wildlife Branch, British Columbia Ministry of Environment and Parks, Victoria, B.C., Canada.

Table 1--Physical and biological parameters that are considered when defining habitat units at various levels in the British Columbia, Ministry of Environment and Parks' Biophysical Habitat Classification

CLASSI-FICATION LEVEL	SURVEY LEVELS & COMMON MAPPING SCALES	CLIMATE	PHYSICAL AND BIOLOGICAL PARAMETERS USED TO DETERMINE HABITAT UNITS AT VARIOUS SCALES			
			TERRAIN	SOILS	VEGETATION	WILDLIFE
ECODOMAIN	Global 1:25 000 000	Broad Climatic similarity	-	-	Broad physiognomic groups (formation-type)	Faunal regions
ECODIVISION	Continental 1:12 000 000	Climate types	Continental Physiography	-	Similar physiognomic groups (formation)	Life zones
ECOPROVINCE	Sub-Continental 1:5 000 000	Macro-climatic processes	Physiographic systems	Soil Orders	Assemblages of vegetation regions and/or zones	Potential wildlife population ranges
ECOREGION	Provincial 1:2 000 000	Macro-climatic processes	Regional physiography	Soil Orders	Vegetation regions (assemblages of vegetation zones)	Wildlife biogeography (historical and potential distribution of populations)
ECOSECTION	Sub-Provincial 1:500 000	Macro-climatic process sub-regions	Regional physiography: regional bedrock	Soil great groups	Vegetation zones	Faunal communities
BIOGEO-CLIMATIC UNITS (ZONES)	Regional 1:250 000	Climatic regimes; macro-climatic parameters	Subdivision of regional physiography to represent groups of local landforms	Soil great groups	Climatic Climax communities	Faunal communities with belts of seasonal habitat use by migratory species
BIO-PHYSICAL HABITAT UNITS	Sub-Regional 1:50 000	Detailed level meso-climatic parameters	Local landforms; topography (slope aspect) parent materials	Soil Sub-groups, few classes (texture, depth, chemistry)	Plant communities (potential successional stages, including climax)	Units of potential seasonal use by migratory species (usually ungulates or grizzly bears)
BIO-PHYSICAL HABITAT UNITS	Watershed 1:20 000	Broad level micro-climatic parameters	Specific landforms and materials, many classes	Soil series, many classes	Plant communities (succession, physiognomy)	Wildlife biology and the influence of social behaviour on distribution and and habitat use
BIO-PHYSICAL HABITAT UNITS	Special Area 1:5 000	Micro-climatic parameters	Materials	phases of soil series	Plant communities many classes	Specific animal use (fish, waterbirds and macroinvertebrates)

REFERENCES

B.C. Ministry of Environment and Parks. 1988. Describing ecosystems in the field. 2nd ed. B.C. Ministry of Environment and Parks, in cooperation with B.C. Ministry of Forests and Lands. Editorial draft.

Demarchi, D.A. 1987. Ecoregions of British Columbia: 1:2 000 000 map. British Columbia Ministry of Environment and Parks, Wildlife Branch, Victoria, B.C.

Demarchi, D.A.; Fenger, M.A.; Lea, E.C.; Harcombe, A.P. 1988. Biophysical habitat mapping methodology, B.C. Ministry of Environment and Parks, Wildlife Branch, Victoria, B.C. Editorial draft.

Demarchi, D.A.; Fuhr, B.; Pendergast, B.A.; Stewart, A.C. 1983. Wildlife capability classification for British Columbia: an ecological (biophysical) approach for ungulates. MOE Manual 4: B.C. Ministry of Environment; Surveys and Resource Mapping Branch, Victoria, B.C. 56 p.

Fuhr, B.L. 1987. A biophysical methodology for grizzly bear assessment in British Columbia. Wildlife Branch, B.C. Ministry of Environment and Parks. Victoria, B.C. Editorial draft. 42 p.

Pojar, J; Klinka, K.; Meidinger, D.V. 1986. Biogeoclimatic ecosystem classification in British Columbia. Internal report for the Ministry of Forests Research Program, Victoria, B.C. 21 p.

THE SOIL-HABITAT TYPE RELATIONSHIP

Maynard A. Fosberg, Minoru Hironaka, and Kent E. Houston

BASIS

Soil and vegetation are functions of the soil-forming equation (Major 1951; Jenny 1958):

$$S, V = f(cl, p, r, o, t)$$

Soil (S) and vegetation (V) are functions of the independent factors climate (cl), parent material (p), relief or topography (r), biota (o), and time (t). The vegetation in this equation refers to the climax plant association. Since the habitat type is based upon the climax plant association, the two can be equated. However, this relationship is only true when the habitat type is supporting climax vegetation and the soil is classified at the series level.

FACTS AND CONCEPTS

* A soil series is associated with only one habitat type. A habitat type, however, can be found on more than one soil series. This is due to the ability of plants to compensate for environmental differences.

* The habitat type is correlated with the soil series and not the family level of soil taxonomy.

* The habitat type correlates to some, but not all, soil characteristics used in soil taxonomy.

* The habitat type is associated with the net effect of all the soil properties.

APPLICATIONS

* Habitat types and soil types should be delineated in concurrent classification programs to achieve the maximum benefit of both systems.

* Habitat types should be used to help delineate the soil series or phase.

* Habitat types can be used to interpret soil moisture and temperature regimes within a local area.

* Habitat types can be used to predict site or soil potential.

SOIL PROPERTIES THAT CORRELATE WITH HABITAT TYPES

Habitat types are primarily associated with the net effect of several soil properties. The most important of these include:

* Soil moisture and temperature regimes
* Depth to restricting layers (clay pans, duripans, or bedrock)
* Type of parent material
* Thickness and color of the surface horizon
* Depth to lime
* Degree of soil development
* Texture
* Clay accumulation
* Mineralogy
* Presence or absence of volcanic ash

Two examples of shrubland-associated soil series from southern Idaho illustrate the importance of these properties. These two soils are distributed on the landscape in a complex mosaic pattern. Knowledge of the effects of the soil characteristics allows the prediction of either habitat type or soil type.

Triangle Series
Artemisia arbuscula/Festuca idahoensis habitat type
Fine-loamy over clayey, mixed, Duric Cryoboroll
Soil Characteristics:

Well-developed clay restricting layer within 12 inches of the surface
Thin, dark surface
Low water holding capacity
Poor root aeration

Caudle Series
Artemisia tridentata spp. *vaseyana/Festuca idahoensis* habitat type

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Maynard A. Fosberg is Professor of Soil Science, University of Idaho, Moscow, ID; Minoru Hironaka is Professor Range Resources, University of Idaho, Moscow, ID; Kent E. Houston is Soil Scientist, Shoshone National Forest, Forest Service, U.S. Department of Agriculture, Cody, WY.

Fine-loamy, mixed Argic Pachic Cryoboroll
Characteristics:

- No restricting layer
- Over-thickened, dark surface layer (high organic matter content)
- High water holding capacity
- Good root aeration
- Relatively uniform texture throughout the soil profile

Two examples of soil series from northern Idaho forests illustrate the importance of these properties. These two soils represent different influences on vegetation from loess and volcanic ash parent materials.

DeMasters Series
Pinus ponderosa/Festuca idahoensis habitat type
Fine-loamy, mixed, frigid, Pachic Ultic Argixeroll
Characteristics:

- Mixed, loess-influenced mineralogy
- Xeric moisture regime
- Over-thickened, dark surface layer (high organic matter)

Unnamed Soil Series
Thuja plicata/Gymnocarpium dryopteris habitat type
Medial over loamy, mixed, frigid, Typic Vitrandept
Characteristics:

- Ash surface mineralogy
- Udic moisture regime
- Light-colored surface layer (low organic matter)

CONCLUSIONS

The soil and habitat type relationships are interrelated and complex. These relationships require that soil scientists and plant ecologists work together to optimize landscape delineation and predictions of management responses.

REFERENCES

Jenny, H. 1958. Role of the plant factor in the pedogenic functions. Ecology. 39: 5-16.

Major, J. 1951. A functional, factorial approach to plant ecology. Ecology. 32: 392-412.

COMPUTERIZED MAPPING OF UTAH'S DISTRIBUTION OF MAJOR PLANT COMMUNITIES

Dan A. Foster and Robert H. Foster

ABSTRACT: The distribution of major plant communities in the state of Utah was computerized, then plotted in map form, using geographic information system (GIS) technology. The computerized plant community information can be used, whole or in part, to rapidly aid in land management decisions and planning in large-scale applications. Data sources, methodology, problems faced, and potential uses are discussed.

INTRODUCTION

One of the major problems of land management in Utah is an accurate assessment of the vegetative cover in the state. In 1985 the Division of State Lands and Forestry in connection with the Automated Geographic Reference (AGR) office began a project to address this problem. The objective of the project was to develop a computerized coverage of the major plant communities in the state on a scale that would allow broad-based land management decisions. Also desired was the ability to increase the map detail by continuous database revision.

METHODS

Computerized mapping of Utah's major plant communities was done in two stages. The first stage was the input of initial mapped information from the dissertation map compiled by Foster (1968). The dissertation map was developed using a combination of aerial photographs and field surveys (Foster 1968). The initial map information was digitized at a scale of 1:500,000 using the ARC/INFO software run on the AGR Prime 550 computer. ARC/INFO is a GIS software package allowing computer graphics, image processing, and computational geometry under ARC, and an extensive data base management system with INFO (Environmental Systems Research Institute 1985; Marble 1984).

The hierarchical letter-number codes of the dissertation map were used to delineate vegetation communities and species within communities and are as follows:

A. Conifer—Aspen
  1. Utah Juniper
  2. Rocky Mountain Juniper
  3. Common Juniper
  4. Pinyon Pine
  5. Singleleaf Pinyon
  6. Aspen
  7. Douglas-fir
  8. White Fir
  9. Subalpine Fir
  10. Blue Spruce
  11. Engelmann Spruce
  12. Ponderosa Pine
  13. Limber Pine
  14. Lodgepole Pine
  15. Bristlecone Pine

B. Mountain Brush
  1. Oak
  2. Maple
  3. Cliffrose
  4. Bitterbrush
  5. Mountain Mahogany
  6. Serviceberry
  7. Squawbush
  8. Choke Cherry
  9. Gooseberry
  10. Currant
  11. Snowberry
  12. Woodrose
  13. Oregon Grape
  14. Ceanothus
  15. Arctostaphylos
  16. Honeysuckle
  17. Box Elder

C. Herbs-Shrubs
  1. Sagebrush
  2. Greasewood
  3. Shadscale
  4. Mat-atriplex
  5. Castle Valley Clover
  6. Rabbitbrush
  7. Horsebrush
  8. Russian Thistle
  9. Pickleweed
  10. Halogeton
  11. Winterfat
  12. Mormon Tea
  13. Snakeweed
  14. Blackbrush
  15. Creosotebush

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Dan A. Foster is Program Manager Utah Wildlife Information Network, Utah Division of Wildlife Resources, Salt Lake City, UT; Robert H. Foster, is a Biogeographer, Provo, UT.

   16. Bursage
   17. Prickly Pear
   18. Buffaloberry
   19. Singleleaf Ash
   20. Fremont Mahonia
   21. Whitetop

D. Grasses-Sedges
   1. Cheatgrass
   2. Ricegrass
   3. Dropseed
   4. Saltgrass
   5. Wheatgrass mix
   6. Galleta
   7. Needlegrass
   8. Foxtail
   9. Bluegrass
   10. Grama
   11. Brome
   12. Three Awn
   13. Trisetum
   14. Fescue
   15. Sedge
   16. Seeded
   17. Reedgrass
   18. Timothy
   19. Crested Wheat
   20. Yucca

E. River Bottom
   1. Fremont Cottonwood
   2. Narrowleaf Cottonwood
   3. Willow
   4. Tamerisk
   5. Russian Olive

F. Cultural Forms
   1. Cities
   2. Cultivated Land

G. Physical Forms
   1. Water
   2. Alkali
   3. Sand
   4. Mud
   5. Wasteland
   6. Playa

This system allows for the delineation of dominant and codominant species by using upper case letters and using lower case letters for related species. This system is similar to, but more detailed than the numerical system used by Küchler (1975). The database management system of ARC/INFO allowed for easy input of the major communities, species within communities, and shade patterns for polygons representing each community. Conversion from this classification system to others is easily facilitated in the software. For example, the more rigid system used by Welsh and others (1987) could be implemented.

By inputting the original map, an automated "snapshot" of the state's vegetative cover was made available for roughly a 20-year comparison of vegetative trends.

The second stage of the project was field surveying to update the original map and input of the new data into the digital database. Extensive field reconnaissance was done to check the status of plant communities and record changes of major distribution throughout the state. ARC/INFO capabilities allowed rapid and accurate line and polygon changes to computerized data of vegetation changes and correction of mapping errors.

The update coverage information on water bodies and rivers was obtained from overlaying the Bureau of Land Management's Areas of Responsibility and Land Status map at 1:500,000 scale (Bureau of Land Management 1975). City information was obtained from the Utah Department of Transportation's General Highway Map series at 1:125,000 scale (Utah Department of Transportation 1975).

RESULTS

Fifty major plant communities were mapped. Eight additional communities were included as cultural an physical forms. Seventy-eight major plant species were included in the coverage. Over 1,200 polygons were created depicting the plant community coverage for the 1968 data and over 1,300 for the update coverage of 1987.

Using a Calcomp 1077 plotter, both the 1968 and 1987 coverages were produced in map form at a scale of 1:750,000. These maps were plotted in 10 colors with 58 shade patterns and included a 1° x 1° tile for latitude-longitude, distance scales, map references, and a full key.

DISCUSSION

Two problems were encountered during the development of the computerized plant community coverage. The first was in the variance of the original base map for automated cartography. Although the original plant coverage and the statewide base maps were at 1:500,000 scales, errors were encountered in the digitization process which showed the publication projections of the maps were actually different. This in effect displaced the registration points of the digitizing and necessitated the transformation of the automated plant coverage to fit the existing computerized state base map. Transformation of the digital data resulted in the "stretching" of polygon features to fit both the X and Y axis of the base map. Extensive cleaning was necessary to repair the effects of the transformation to ensure that polygo features resided in the proper areas, that is, river bottoms matched the river drainages, and so on.

The second problem encountered was the lack of current digital or hard-copy-mapped information available to us in building an up-to-date coverage. The coverages used to build the water bodies and city areas were not as recent as desired, but were used out of necessity.

As mentioned before, a 20-year vegetation trend comparison was made for the state which showed that major increases have been made by some communities of grasses, specifically in the cheatgrass encroachment of shrubland. Other changes can also be seen.

Automated capabilities enable the plant coverage to be used for such studies as range trend, impact analysis, and mitigation procedures. The limiting factors to usage are the availability of associated study coverages and the desired scale of output. With continual update the scale of output can be decreased to reflect greater map accuracy.

REFERENCES

Bureau of Land Management. 1975. Areas of responsibility and land status: Bureau of Land Management. 1:500,000; Polyconic projection; colored.

Environmental Systems Research Institute 1985. ARC/INFO users manual. Redlands, CA: Environmental Systems Research Institute. Version 3.2.

Foster, Robert H. 1968. Distribution of the major plant communities in Utah. Provo, UT: Brigham Young University. 124 p. Dissertation.

Küchler, A.W. 1975. Potential natural vegetation of the conterminous United States. American Geographical Society. 1:3,168,000; Lambert conformal conic projection; colored.

Marble, Duane F. 1984. Geographic information systems; an overview. IEEE. CH2079-2: 18-24.

Utah Department of Transportation. 1975. General highway maps. Utah Department of Transportation. 1:125,000; Polyconic projections; colored.

Welsh, S.L.; Atwood, N.D.; Goodrich, S.; Higgins, L.C., ed. 1987. A Utah flora. Great Basin Naturalist. Memoir No. 9. 894 p.

PLANT COMMUNITY CLASSIFICATION OF EL MALPAIS, NEW MEXICO

Richard E. Francis and Tod B. Williams

ABSTRACT: Twenty-seven sites on El Malpais were quantified and classified into 19 existing plant communities representing 3 formations and 7 subformations. The plant communities form an ecological data base for management.

INTRODUCTION

El Malpais (lava flow badlands) is located south of Grants in west-central New Mexico. The study area is approximately 34,000 ha in size with elevations ranging from 2154 to 2360 m. The mean annual precipitation is between 227 and 357 mm. Four lava flows are bordered on the east by sandstone bluffs and on the west by numerous volcanic cones. The oldest flow was about 3,000 years ago, and the newest is about 800 years old (USDI BLM 1982; Armstrong 1983). The soils are exposed lava flows (basalt) surrounded by shallow to moderately deep soils on several landforms.

The objective of our study was to quantify and classify the existing plant communities directly on, or influenced by, the lava flows. The intent of this paper is to provide an approach to plant community classification using El Malpais as an example.

METHODS

Twenty-seven homogeneous sample sites were selected on and around the lava flows. The sites were selected as being representative of the area and three permanent transects were established at each site. The sites were sampled using 100 5x10-cm microplots (Morris 1973) per transect for foliar cover, and 10 0.5-m^2 circular plots per transect for density and frequency, collectively known as Community Structure Analysis (CSA) (Pase 1981). The CSA estimates included bare soil, litter, and rock. Importance values (IV) for plant species were calculated from relative foliar cover, relative density, and relative frequency; maximum IV=3.0. IV's ≧ 0.1 were used to calculate resemblance matrices consisting of dissimilarity coefficients derived from Euclidean distance coefficients (Sneath and Sokal 1973; Romesburg 1984).

A dendrogram was produced using Ward's (1963) clustering method from Program CLUSTAN (Wishart 1981) based on the minimum variance between two sites (Romesburg 1984). The cluster routine followed a hierarchical-agglomerative-polythetic approach (Goodall 1978; Romesburg 1984). The resultant dendrogram (fig. 1) was interpreted for realistic clusters using individual site summaries (table 1), successive approximation (Poore 1962), and site photos. Herbaceous production was estimated by double sampling 10 0.89-m^2 plots per transect; estimates were made by species and total weight.

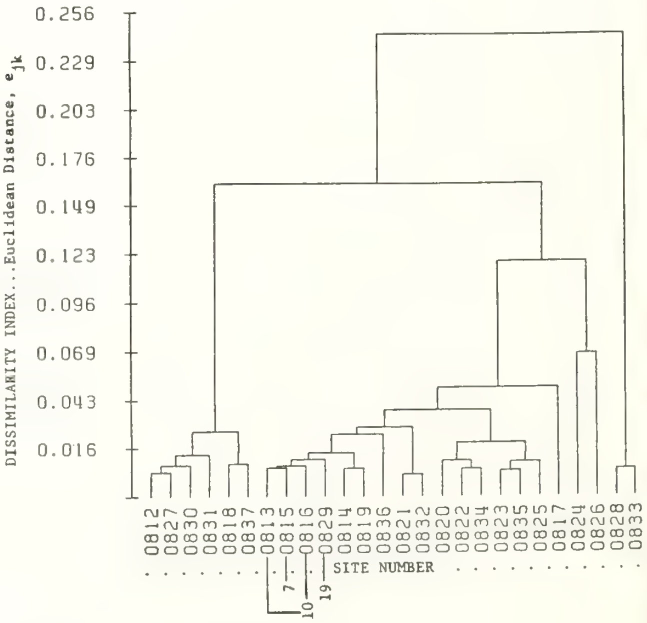

Figure 1--Dendrogram of 27 El Malpais sites using species IV ≧ 0.1. Connected sites represent 3 of the 19 plant communities: P.C. 7, 10, and 19.

RESULTS

Nineteen existing plant communities (table 2 and 3) were described following interpretation of dendrogram clusters, site summaries, and supplemental information. The 19 communities

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Richard E. Francis is Range Scientist and Tod B. Williams is Research Range Technician, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM.

Table 1--Partial site summary of species variables from 4 El Malpais sites following the horizontal dendrogram x-axis. Underlined species were used to form and name the plant community (P.C.)

P.C. no.	Site no.	Species[1]	Foliar cover (%)	Density (no.)	Frequency (%)	IV	Herbaceous production (kg/ha)
10	813	Bogr	7.2	22.8	97	0.623	140
		Annu	3.8	23.4	87	.514	10
		Lich	3.9	10.8	63	.333	
		Sihy	3.3	5.2	80	.267	15
		Semu	1.4	6.9	50	.193	56
		Gusa	1.8	2.5	67	.172	127
		Hyri	1.9	0.8	37	.116	
		Teca	1.5	0.4	33	.096	
		Other	8.2	32.6		.686	31
			33.0	82.0		3.000	379
7	815	Bogr	4.0	21.5	93	.648	94
		Annu	1.0	9.6	73	.315	6
		Lich	2.7	6.8	63	.306	
		Gusa	3.1	4.1	67	.279	165
		Pied	6.8	0.1	7	.235	
		Arca	2.3	4.1	37	.203	
		Jumo	4.3	0.1	3	.146	
		Sihy	0.7	2.2	33	.113	13
		Hyri	1.2	0.6	37	.108	
		Other	3.9	9.9		.647	118
			30.0	59.0		3.000	396
10	816	Bogr	4.1	34.7	93	.638	59
		Gusa	8.1	11.5	97	.517	522
		Lich	5.5	18.5	90	.501	
		Annu	1.8	13.2	93	.328	29
		Leer	1.0	3.1	60	.146	
		Chpa	2.6	0.2	20	.115	
		ERIG	0.3	1.9	60	.111	
		Spco	0.5	1.2	57	.107	
		Teca	1.1	0.4	30	.078	
		Other	6.0	6.3		.459	590
			31.0	91.0		3.000	1200
19	829	Bogr	7.0	46.1	83	.882	76
		Lich	4.9	15.3	60	.434	
		Arfr	5.8	2.9	60	.330	56
		Gusa	3.5	3.3	87	.301	290
		ERIG	1.4	4.5	53	.185	
		Annu	0.5	1.9	63	.144	
		Other	5.9	17.0		.724	193
			29.0	91.0		3.000	615

[1] Plant communities and species binomial symbols are listed in tables 2 and 3, respectively.

represented 3 formations (dominant lifeform) and 7 subformations (dominant genus).

Site summaries were an integral part of interpreting and adjusting the dendrogram clusters. For example, at dissimilarity index 0.016, sites number 813, 815, 816, and 829 were directly linked (fig. 1); the first three sites were dominated by Bogr (IV>0.6), Gusa (IV>0.1), and Lichen (IV>0.3) (table 1). However, that dominance was considered modified by the presence of other lifeform synusia: sites 813 and 816 with Teca (IV∿0.1), a shrub, and site 815 with the presence of two trees, Pied (IV>0.2) and Jumo (IV>0.1). Therefore, the three sites were recombined to form two distinct communities based on lifeform synusia and associated variables (P.C. 7 and 10). Site 829 was considered distinct by the dominance of Arfr (IV>0.3) and Gusa (IV>0.3) in association with Bogr (IV>0.8) and named P.C. 19 (table 1).

The range of site variables were 1) foliar cover 30-60%, 2) bare soil 0-87%, 3) litter 10-51%, 4) rock 0-57%, and 5) herbaceous production 60-1,200 kg/ha.

Table 2--Existing plant communities of El Malpais, New Mexico. Species dominance was based on an importance value ≥ 0.1 calculated from relative foliar cover, relative density, and relative frequency

FORMATION	SUBFORMATION	COMMUNITY[2]
TREELAND	Pinus	1. Pipo/Mumo-Bogr
		2. Pipo/Mumo-Bltr
		3. Pipo/Mumo-Pofe
		4. Pipo/Fapa/Bogr
		5. Pied/Quun/Mumo
		6. Pied/Gusa/Bogr/Lich
		7. Pied-Jumo/Bogr/Lich
	Juniperus	8. Jumo/Bogr-Spcr
		9. Jumo/Gusa/Bogr
SHRUBLAND	Tetradymia	10. Teca-Gusa/Bogr/Lich
		11. Teca-Gusa/Hyfi/Bogr
	Artemisia	12. Arfi/Bogr
	Chrysothamnus	13. Chnab/Bogr
		14. Chnab-Gusa/Spcr
	Fallugia	15. Fapa-Chvi/Ansc
GRASSLAND	Bouteloua	16. Bogr/Spco-Agsm
		17. Gusa/Bogr/Lich
		18. Gusa-Chpa/Bogr
		19. Arfr-Gusa/Bogr

[2] See Table 3 for species binomials.

Table 3--Plant species symbols and binomials used in naming El Malpais plant communities. Taxonomy follows Nickerson and others 1976; Martin and Hutchins 1980

Species symbol	Species binomial
Agsm	Agropyron smithii
Ansc	Andropogon scoparius
Annu	Annuals
Arca	Artemisia carrutherii
Arfi	Artemesia filifolia
Arfr	Artemisia frigida
Bltr	Blepharoneuron tricholepis
Bogr	Bouteloua gracilis
Chnab	Chrysothamnus nauseosus ssp. bigelovii
Chpa	Chrysothamnus parryi
Chvi	Chrysopsis villosa
ERIG	Erigeron spp.
Fapa	Fallugia paradoxa
Gusa	Gutierrezia sarothrae
Hyfi	Hymenopappus filifolius
Hyri	Hymenoxys richardsonii
Jumo	Juniperus monosperma
Lich	Lichen
Mumo	Muhlenbergia montana
Pied	Pinus edulis
Pipo	Pinus ponderosa
Pofe	Poa fendleriana
Semu	Senecio multicapitatus
Sihy	Sitanion hystrix
Spco	Sphaeralcea coccinea
Spcr	Sporobolus cryptandrus
Teca	Tetradymia canescens
Quun	Quercus undulata

CONCLUSIONS

Results of this study form an ecological data base of quantitative community descriptions (Francis 1986) to interpret and monitor successional stage and management prescriptions, and to form a monitoring base for ecosystem dynamics (trend). The data also provide a quantitative base to establish the relationship of plant communities to soils and landform. The study is applicable to the management and subsequent evaluation of similar environments.

ACKNOWLEDGMENT

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REFERENCES

Armstrong, Ruth. 1983. El Malpais: A black and broken sea. New Mexico Magazine. 61(11): 30-35, 82.

Francis, Richard E. 1986. Phyto-edpahic communities of the upper Rio Puerco watershed, New Mexico. Res. Pap. RM-272. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 73 p.

Goodall, David W. 1978. Numerical classification. In: Whittaker, Robert H., ed. Classification of plant communities. The Hague: Dr. W. Junk bv Publishers: 247-286.

Martin, William C.; Hutchins, Charles R. 1980. A Flora of New Mexico. Hirschberg, Germany: J. Cramer: 2591 p. 2 vols.

Morris, Meredith J. 1973. Estimating understory plant cover with rated microplots. Res. Pap. RM-104. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Nickerson, M. F.; Brink, G. E.; Feddema, C. 1976. Principal range plants of the central and southern Rocky Mountains: Names and symbols. Gen. Tech. Rep. RM-20. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 121 p.

Pase, C. P. 1981. Community structure analysis--a rapid, effective range condition estimator for semi-arid ranges. In: Lund, H.G. and others, tech. coords. Arid land resource inventories: Developing cost-efficient methods. Gen. Tech. Rep. WO-28. [Nov. 30-Dec. 6, 1980, La Paz, Mexico]. Washington, DC: U. S. Department of Agriculture, Forest Service: 425-430.

Poore, M. E. D. 1962. The method of successive approximation in descriptive ecology. In: Cragg, J. B., ed. Advances in Ecological Research, Vol. 1. New York: Academic Press: 35-68.

Romesburg, H. C. 1984. Cluster analysis for researchers. Belmont, CA: Lifetime Learning Publications: 334 p.

Sneath, P. H. A.; Sokal, R. R. 1973. Numerical taxonomy. San Francisco, CA: W. H. Freeman and Co.: 573 p.

USDI Bureau of Land Management. 1982. West Socorro rangeland management program. Draft environmental impact statement. Socorro, NM: U. S. Department of Interior, Bureau of Land Management. Four chapters and appendices.

Ward, J. H., Jr. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association. 58(301): 236-244.

Wishart, D. 1981. CLUSTAN user manual. Edinburg, Scotland: Program Library Unit: 174 p.

SOIL FUNGI: AN ADDITIONAL PARAMETER
FOR PHYTO-EDAPHIC COMMUNITY CLASSIFICATION

P. R. Fresquez, G. L. Dennis, and R. E. Francis

ABSTRACT: The utility of soil fungi in phyto-edaphic community classification was tested by determining the relationships between the soil fungal communities and the physiochemical properties of soils associated with plant communities in the semiarid Southwestern United States. Populations of fungi were significantly higher in soils from treeland plant communities as compared to shrub or to grassland plant communities. In contrast, the diversity of fungal groups was higher in the shrub and grassland plant communities than in the treeland plant communities. The community composition of fungal groups differed considerably among the three major plant life-forms, indicating that the soils from each plant community had a distinct fungal community composition. Fungal parameters in association with the soils chemistry offer a useful means of describing ecosystem dynamics, in terms of identifying more productive soils, and/or soils that are physiochemically stressed.

INTRODUCTION

Traditionally, land classification has been based on the description of plant communities or the identification of plant communities associated with specific soils (i.e., phyto-edaphic classification) (Daubenmire 1970, Mueggler and Stewart 1980, Youngblood and Mueggler 1981, Tiedeman and others 1987). A more ecologically sound classification of phyto-edaphic communities should result from quantifying and describing the biotic component of the belowground ecosystem as well. Soil microbial populations respond more rapidly to changes or to fluctuations in the soil environment than do plants (Atlas and Bartha 1981). Determining soil microbial parameters in association with soil physical and chemical characteristics may help to describe ecosystem dynamics in terms of identifying more productive soils, or soils that are physiochemically stressed (Fresquez and others 1986).

Soil fungal populations, diversity, and community composition are related to soil properties as influenced by vegetation (Tresner and others 1954, England and Rice 1957, Mallik and Rice 1966, Badurowa and Badura 1967, Wicklow and others 1974, Christensen 1981). Such site-specificity should make soil fungi a useful additional parameter to better describe and interpret phyto-edaphic communities. In this preliminary study, the utility of soil fungi in phyto-edaphic community classification was tested by determining the relationships between the soil fungal communities and the physiochemical properties of soils associated with plant communities in the semiarid Southwest.

MATERIALS AND METHODS

Forty-five plant communities have been quantified and classified in the Upper Rio Puerco Watershed of northwestern New Mexico (Francis 1986). Of the 45 communities, 11 were considered the most representative--2 treeland, 5 shrubland, and 4 grassland types:

- Treeland plant communities
  1. *Pinus ponderosa/Carex filifolia - Bouteloua gracilis*
  2. *Juniperus monosperma/Bouteloua gracilis*
- Shrubland plant communities
  3. *Artemisia tridentata - Gutierrezia sarothrae/Bouteloua gracilis - Agropyron smithii*
  4. *Chrysothamnus parryi/Bouteloua gracilis - Agropyron smithii*
  5. *Sarcobatus vermiculatus/Sitanion hystrix - Hilaria jamesii*
  6. *Ceratoides lanata - Gutierrezia sarothrae/Hilaria jamesii*
  7. *Atriplex canescens/Sporobolus airoides - Sitanion hystrix*
- Grassland plant communities
  8. *Gutierrezia sarothrae/Bouteloua gracilis - Hilaria jamesii*
  9. *Gutierrezia sarothrae/Hilaria jamesii - Bouteloua gracilis*
  10. *Sporobolus airoides - Bouteloua gracilis*
  11. *Scleropogon brevifolius - Bouteloua gracilis*

Each selected plant community contained a minimum of three 180-m permanent line transects from which soils were sampled in August 1986. Soil samples were analyzed for numerous physical and chemical properties as well as the numbers and types of soil fungi (Fresquez and others 1987).

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Philip R. Fresquez is Soil Microbiologist, Glen L. Dennis is Research Assistant, and Richard E. Francis is Range Scientist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Albuquerque, NM.

Variations in the soil physical and chemical variables and in the populations of soil fungi from the three plant formations were analyzed using one-way analysis of variance. The Least Significant Difference (L.S.D.) test ($p \leq 0.05$) was used to compare soil parameters and fungal population means among the formations. Also, Pearson's correlation coefficients were used to compare fungal populations with soil chemical parameters among the formations. Three indexes were used to compare the distribution patterns of soil fungal groups among the plant formations: Shannon's index of species diversity and an associated evenness index (Greig-Smith 1983) and Sorenson's presence community coefficient (SPCC) (Mueller-Dombois and Ellenberg 1974).

RESULTS AND DISCUSSION

Soils associated with treeland plant communities had significantly higher fungal populations compared to soils associated with shrub or grassland plant communities (table 1). Increasing numbers of fungal propagules in the treeland communities were significantly correlated with decreasing soil pH and with increasing total N, P, and organic matter (Fresquez and others 1987). In contrast, the diversity and evenness of fungal groups were higher in soils from the shrub and grassland plant communities than in soils from the treeland plant communities. Lower populations of fungi and higher fungal diversities in the shrub and grassland plant communities were associated with a lower soil organic matter status compared to the more organic matter rich treeland plant communities.

The composition of fungal groups differed considerably among the soils from the three major plant formations, indicating that each had a distinct fungal community composition. Based on Sorensen's presence community coefficient, the similarity of fungal groups among the soils from the three major plant growth forms was very low. Soil fungal communities associated with the treeland plant communities were more similar to the fungal communities associated with the grasslands (44%) than to those found in the shrublands (35%). The differences in the composition of fungal groups among the three major plant growth forms were not unexpected. Because of the differences in the amounts and types of plant materials produced by the different plant communities, the amount and type of fungi occupying a given site should change (Badurowa and Badura 1967). For example, the combined soil microfungi from both of the treeland plant communities could be readily distinguished from the shrub and grassland soil fungi. Treeland soils characteristically yield a greater diversity of *Penicillium* species, which usually constitute a relatively higher proportion of the total isolates (States 1978, Christensen 1981). Although *P. cyclopium* dominated the soils from both the tree and shrubland plant communities, the overall similarity in the composition of the fungal communities of these two plant formations was still very low (35%). In comparison to the soils from the tree and shrubland formations, the grassland plant communities were dominated or codominated by the genus *Fusarium*, which is characteristic of grassland plant communities (Christensen 1981).

The differences in populations, diversities, and the composition of fungal groups among the three major plant growth forms were probably due to the wide differences in the composition of the plant communities themselves, soil surface characteristics, and to differences in the chemical and physical properties of the soils (Fresquez and others 1987). The treeland plant communities had significantly higher fungal populations and a lower diversity of fungal groups, probably a result of the significantly higher organic matter concentrations, plant cover, and litter and decreased amounts of exposed soil compared to the soils from the shrubland or the grassland plant

Table 1--Fungal parameters associated with soils from three major plant life-forms occurring in the semiarid Southwest

Fungal parameters	Treeland	Shrubland	Grassland
Propagules (10^3/g)	177 a[1]	34 b	32 b
Diversity	0.81	0.86	0.94
Evenness	0.67	0.72	0.76
Dominant groups	*Penicillium cyclopium*/ *P. funiculosum*/ *P.* unidentified	*P. cyclopium*/ *Aspergillus ochraceous*/ *A. fumigatus*	*Fusarium* spp./ *A. fumigatus*/ *A. ochraceous*
Similarity coefficients			
Treeland		35	44
Shrubland			34

[1] Means within the same row followed by the same letter are not significantly different at the 0.05 level by the Least Significant Difference (L.S.D.) test.

communities. The lower soil organic matter and surface characteristics of the shrub and grassland plant communities probably led to decreased fungal populations, but increases in the number of fungal groups. Some shrub (i.e., Atriplex canescens/Sporobolus airoides - Sitanion hystrix) and grassland (i.e., Gutierrezia sarothrae/Bouteloua gracilis - Hilaria jamesii) communities, however, had lower soil fungal diversities because of adverse soil chemical and physical properties (as opposed to a low fertility status) and/or adverse soil surface conditions that probably resulted in increases in soil temperature and decreases in the amount of available soil moisture.

CONCLUSIONS

Soil fungi (their population size, diversity and community composition) offer a useful method to help delineate phyto-edaphic communities. In this preliminary study, different fungal communities were clearly associated with soils having different plant formations (i.e., tree, shrub, and grasslands). From a resource management perspective, fungal population size and diversity indices may be a useful means of describing ecosystem dynamics (i.e., trends), in terms of identifying more productive soils, and/or identifying or expressing the degree of soil physiochemical stress that is being placed on the soil-plant ecosystem.

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REFERENCES

Atlas, R.M.; Bartha, R. 1981. Microbial ecology: Fundamentals and applications. Reading, MA: Addison-Wesley. 560 p.

Badurowa, M.; Badura, L. 1967. Further investigations on the relationship between soil fungi and the macroflora. Acta Societies Botanicorum Polanial. 35: 515-529.

Christensen, M. 1981. Species diversity and dominance in fungal communities. In: Wicklow, D.T.; Carroll, G.C.; ed. The fungal community. New York, NY: Marcel Dekker: 201-232.

Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agricultural Experiment Station Technical Bulletin 62. Pullman, WA: Washington State University. 131 p.

England, C.M.; Rice, E.L. 1957. A comparison of the soil fungi of a tall grass prairie and of an abandoned field in central Oklahoma. Botanical Gazette. 118: 186-190.

Francis, R.E. 1986. Phyto-edaphic communities of the Upper Rio Puerco Watershed, New Mexico. Res. Pap. RM-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 73 p.

Fresquez, P.R.; Aldon, E.F.; Lindemann, W.C. 1986. Microbial reestablishment and the diversity of fungal genera in reclaimed coal mine spoils and soils. Reclamation and Revegetation Research. 4: 245-258.

Fresquez, P.R.; Francis, R.E.; Dennis, G.L. 1987. Fungal communities associated with phyto-edaphic communities in the semiarid Southwest. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM.

Greig-Smith, P. 1983. Quantitative plant ecology. Berkeley, CA: University of California Press. 359 p.

Mallik, M.A.; Rice, E.L. 1966. Relation between soil fungi and seed plants in three successional forest communities in Oklahoma. Botanical Gazette. 127: 120-127.

Mueggler, W.F.; Stewart, W.L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York, NY: Wiley. 547 p.

States, J.S. 1978. Soil fungi of cool-desert plant communities in northern Arizona and southern Utah. Arizona Academy of Science. 13: 13-17.

Tiedeman, J.A.; Francis, R.E.; Terwilliger, C. Jr.; Carpenter, L.H. 1987. Shrub-steppe habitat types of Middle Park, Colorado. Res. Pap. RM-273. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p.

Tresner, H.D.; Backus, M.P.; Curtis, J.T. 1954. Soil microfungi in relation to the hardwood forest continuum in southern Wisconsin. Mycologia. 46: 314-333.

Wicklow, M.C.; Bollen, W.B.; Denison, W.C. 1974. Comparison of soil microfungi in 40-year-old stands of pure alder, pure conifer, and pure alder-conifer mixtures. Soil Biology and Biochemistry. 6: 73-78.

Youngblood, A.P.; Mueggler, W.F. 1981. Aspen community types on the Bridger-Teton national forest in western Wyoming. Res. Pap. INT-272. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 83 p.

MULTISPECTRAL LANDCOVER CLASSIFICATION:

AN OVERVIEW OF AN OPERATIONAL ALTERNATIVE

Steven J. Gill, Judy A. Hart, and David B. Wherry

ABSTRACT: Over the past two decades resource management agencies have required ever greater amounts of geographic data. The traditional methods used to acquire these data have increased greatly in cost while budgets have become progressively more limited. Landcover classifications based on digital satellite data provide an efficient and cost-effective alternative to costly aerial photo and ground mapping techniques. This paper provides an overview of the methods used to develop a multispectral landcover classification for use in multilayered Geographic Information Systems.

INTRODUCTION

During the past two decades resource management agencies have required ever greater amounts of information to meet mandated management objectives. Over this same period, the cost of traditional data acquisition and analysis methods has increased dramatically, while budgets have become increasingly constrained. The net result of this trend for large-scale land classification and habitat analysis projects is that traditional aerial photography and extensive ground mapping techniques are no longer cost effective, nor feasible in many cases, for accomplishing project goals.

Digital image analysis techniques offer resource management and planning agencies an efficient and cost-effective alternative to traditional resource mapping and analysis methods. Well designed digital databases have several additional advantages. They allow easy update of information in the system, and the database may be queried for diverse applications without costly and time-consuming data replication.

In the Pacific Northwest, a variety of operational land management database projects have taken the form of Landsat based Geographic Information Systems (GIS). Typically, these databases consist of several dataplanes, including a Landsat based landcover classification; topographic information derived from USGS digital terrain models; roads, streams, trails, etc., digitized from USGS 7.5 minute quad maps; and timber harvest, land ownership, etc., derived from agency maps and records. Once these maps have been converted to digital database format, the GIS may be used to answer a wide variety of complex management and research questions.

THE DIGITAL IMAGE ANALYSIS LABORATORY

Washington State University's (WSU) Digital Image Analysis Laboratory (DIAL) provides systems support, training, project design, and implementation services to a wide variety of users from the scientific, resource management, and administrative sectors. DIAL users include WSU educators and researchers, as well as remote sensing and geographic information system professionals at federal, state, and local agencies and businesses in the Pacific Northwest. DIAL provides experienced consulting, training, and a powerful combination of batch and interactive image processing hardware and software.

DIAL Service Philosophy

The DIAL service philosophy emphasizes the training of individuals to carry out their own image analysis computing applications. A training course introduces the user to image processing concepts, facilities, and accessibility. Initial application work often involves significant consulting support from DIAL staff. Consulting requirements then rapidly diminish with increasing user project work until self-sufficiency is achieved.

This service philosophy is somewhat unique among private and public image processing facilities, most of which make it their business to provide the user with products, not computing support. Generally users are intimately familiar with their own applications and thus have the greatest capabilities in formulating research problems, designing analysis strategies, and generating final products. While situations do arise in which DIAL staff generate products and design analysis strategies, these cases are always driven directly by user specifications.

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Steven J. Gill is Applications Specialist, Judy A. Hart is Systems Analyst and David B. Wherry is Director, Digital Image Analysis Laboratory, Washington State University, Pullman, WA.

DIAL Systems Capabilities

DIAL provides its users with a variety of data capture, processing, and output systems. A combination of image processing, graphics, and product generation capabilities provides a well rounded complement of tools for those interested in image analysis and GIS technologies. These tools include batch/ mainframe image and GIS processing, interactive image analysis and display, interfaces to graphics processing, access to commercial scanning services, X-Y coordinate digitizing, graphics data manipulation, interfaces to image processing, graphics display and plotting, Polaroid photographic products, overnight 35mm slides, and color pen plots.

Mainframe Image Processing--The workhorse of DIAL's image processing capability is the batch-oriented VICAR/IBIS image processing software package. With more than 150 modular functions and running on WSU's IBM 3090-200 mainframe computer system, VICAR/IBIS provides abundant processing flexibility as well as exceptional efficiency (cost effectiveness) in processing large and small image datasets alike. VICAR/IBIS capabilities are accessible to all DIAL users simultaneously on the multi-user mainframe computer. Access is made possible by WSU telecommunications systems linking users at WSU and throughout the Western United States to the DIAL facility in Pullman, Washington.

Interactive Processing--With DIAL's interactive system, users are aided by immediate color display of their image processing results. Within the display/analysis session, images can be previewed, processing strategies can be designed to meet research requirements, and intermediate and final analysis products can be displayed for verification and/or photographic recording. A VAX super minicomputer and specialized image processing hardware provide the computing power which optimizes the real time display/analysis sessions at this WSU-based facility.

AN OVERVIEW OF SATELLITE BASED LANDCOVER CLASSIFICATION

Usually the development of the land classification layer of the GIS is one of the most complex tasks of the database development and it is to this topic that most of this paper is devoted. Once the project study area has been identified, there are several steps to a successful satellite-based classification:

1. Project design
2. Digital data acquisition
3. Ground data acquisition
4. Definition of training statistics through statistical analyses
5. Application of the training statistics though the classification algorithm
6. Assessment and evaluation of the classification
7. Refinement of the classification (if necessary) using ancillary data
8. Assessment and evaluation of the revised classification
9. Integration of the classification with other data planes of the GIS
10. Production of output products

PROJECT DESIGN

There are several points to consider when designing projects using satellite data. These include:

1. The cost/benefit ratio of using Landsat or other satellite technology compared with other data collection methods. The cost savings tend to be most dramatic with relatively large and/or mostly inaccessible study areas.
2. The ability of satellite and ancillary data inputs to provide the required output products. For example, Landsat only "sees" the overstory of heavily forested plant communities. If the project requires information on understory composition, the researcher must be certain that he or she can correlate the overstory cover type with the appropriate understory assemblage. (This can often be accomplished by stratifying the Landsat spectral classification with topographic data, but more on this later.)
3. What types of ground data and ancillary digital data are necessary and available to the project.
4. What types of output products will be required.

DIGITAL DATA ACQUISITION

To date several satellites have been launched that return publicly accessible earth imagery. Most prominent among these are the five Landsat satellites launched by the U.S., and SPOT, which was recently placed into operation by the French. The instantaneous field of view, or picture element (pixel) size, of these satellites varies from 80 meters on a side to 10 meters, depending on the type of imagery used. More details on the Landsat satellites and their data may be obtained in Freden and Gordon (1983), and the September 1985 issue of "Photogrammetric Engineering and Remote Sensing", which was devoted to Landsat Image Data Quality Analysis. Landsat data are available from the EOSAT Corporation, Lanham, MD., and SPOT data from the SPOT Image Corporation, Reston, VA. The Digital Image Analysis Laboratory maintains archived Landsat imagery for all of Washington and portions of Idaho, Oregon, and British Columbia.

Two types of digital terrain data are available from the National Cartographic Information Center in Reston, VA. The first is U.S. Geological Survey 7.5 minute digital elevation model (DEM) data. These data correspond to USGS 7.5 minute quadrangle maps. The second format is Defense Mapping Agency (DMA) data. These data are available in 1° x 1° blocks. DIAL has a complete set of DMA data for the state of Washington and northeastern Oregon, as well as portions of the Idaho panhandle. Both Landsat and DMA data are available to agencies conducting projects at DIAL.

GROUND DATA ACQUISITION

It cannot be emphasized too strongly that at least one project participant must be thoroughly familiar with the area to be classified using satellite imagery. If this is not the case, gross classification errors will likely occur. DIAL's service philosophy of training individuals and project teams to carry out their own image analysis computing applications does much to resolve this potential problem, as those most familiar with the project area are actively involved in its execution.

DEFINITION OF TRAINING STATISTICS--MULTISPECTRAL CLASSIFICATION

Basic requirements for multispectral classifications are that there exist two or more bands (multispectral components) which are spatially aligned (registered) and that the data analyst performing the classification have an adequate grasp of the imagery through ancillary aids such as ground data and familiarity with the study area or image subject. Landsat MSS imagery provides four bands of data per image and Landsat TM data provides six reflective bands plus a band of thermal infrared data. These data are routinely used in multispectral classification projects, both at DIAL and worldwide.

The principle involved in multispectral classification is called pattern recognition (Castleman 1979). Every object reflects electromagnetic energy (light) in a characteristic set of wavelengths which can aid in distinguishing that object from other objects. The distinguishing set of spectral characteristics of an object are called the object's "spectral signature," or more correctly, its "spectral response pattern" (Hoffer 1979). In digital image processing, spectral patterns are defined using means, variances, and covariances as descriptive statistics. These class statistics are then applied to the multispectral data through a classification algorithm that assigns each pixel to a response pattern class based on the pixel's similarity to that pattern.

There are a number of approaches to the problem of defining the statistical groupings or spectral classes used to classify digital imagery. At conceptually opposite ends are the "supervised" and "unsupervised" methods (Fleming and others 1975; Schowengerdt 1983:142). More familiar analogous techniques are discriminant and cluster analysis, respectively. In the supervised approach, the analyst selects numerous areas of homogenous cover type and specifies these sites as "training" areas. The statistics that define spectral classes for a given cover type are produced by aggregating similar training areas. A final set of classification statistics is obtained by accumulating the statistics for all cover types.

The unsupervised approach utilizes a cluster algorithm which divides multi-dimensional image data into a number of spectrally distinct statistical groupings. In this scheme, the analyst supplies the cluster algorithm with controls such as the number of desired spectral classes, minimum acceptable statistical separability, and an image sampling scheme. The resulting spectral class statistics are used to classify the image data. Identification of the cover type(s) represented by each spectral class is accomplished after the classification is completed.

Numerous approaches to spectral class definition employ variations on the supervised and unsupervised methods. The effectiveness of a given approach depends to a large extent on the nature of the area to be classified. In most remote sensing applications, combinations of the supervised and unsupervised techniques are often advantageously used (Schowengerdt 1983:147-149). Hoffer (1979) outlined six methods and compared them for total cost, analyst and computer time used and accuracy. Traditionally, the supervised technique is probably the most commonly used method, although Hoffer (1979) found this approach resulted in the lowest classification accuracy and had the highest cost per unit area of the methods tested. The technique giving the highest classification accuracy is known as the multi-cluster blocks technique (Hoffer 1979). Fortuitously, this method was also one of the least expensive of those tested (Hoffer 1979). The multi-cluster blocks method is a hybrid of supervised and unsupervised clustering techniques. It is similar to the supervised approach in that statistics are developed from training areas of known cover type. The training areas are, however, heterogeneous blocks of data. By judiciously selecting training areas, the analyst can ensure that all significant variations in spectral response for each cover type are represented in the classification statistics. Thus, the major limitations of both the supervised and unsupervised methods are to a large extent overcome. Each of these major approaches to classification statistics are used at DIAL based on individual project requirements. Guidelines for the use of the multi-cluster blocks technique may be found in Gill and Hart (1984).

APPLICATION OF TRAINING STATISTICS TO MULTISPECTRAL IMAGERY

Once class characteristics have been determined, the individual pixels must be assigned to the appropriate category. VICAR provides two programs for making pixel assignments: BAYES, which uses the maximum likelihood algorithm (Hart and Wherry 1984, v. 2:33-35, v. 4:7-8); and FASTCLAS, which uses the parallelepiped and, optionally, the maximum likelihood techniques (Hart and Wherry 1984, v. 2:97-99, v. 4:31). The maximum likelihood classifier is a parametric approach that requires the calculations for each pixel of the probability that it belongs to each of the defined classes (Hart and Wherry 1984 v. 4:7-8; Schowengerdt 1983: 176). This method quantitatively evaluates the variance and correlation of the multidimensional clusters when classifying an unknown pixel (Estes and others 1983:1045). Each pixel is then assigned to the class for which membership is most likely. Because the maximum likelihood method is parametric, it assums a normal distribution. The parallelepiped method is nonparametric, and thus makes no assumption about class distributions (Schowengerdt 1983:176-177). When FASTCLAS is used under the hybrid parallelepiped/maximum likelihood option, unambiguous pixels are classified with the parallelepiped algorithm and the maximum likelihood algorithm is only invoked to resolve ambiguities when a pixel is located within two or more parallelepiped decision boundaries (Hart and Wherry 1984, v. 2:97-99, v. 4:31).

CLASSIFICATION EVALUATION AND DESIGNATION OF INFORMATION CLASSES

To maximize the usefulness of the classified image, spectral classes must be aggregated into information classes. It is often desirable to define several spectral classes for a single cover type in order to account for the natural variation in spectral response within that cover type. Thus, there are generally several spectral classes assignable to each cover type in the classified image. Therefore, spectrally classified images are simplified by assigning each spectral class to an information class appropriate to the project's information requirements. It is at this point that access to complete and accurate ground data becomes especially important. Enough good data must be available to accurately assign each spectral class to an information class.

Spectral classes often are not uniquely correlated with a desired information category. This can be particularly true in areas of rugged terrain where slope and aspect as well as cover type affect the spectral characteristics of a given pixel. A classic example of this problem is the inability to entirely distinguish water from dark shadows using Landsat MSS data alone. Stratification of the classified Landsat data with terrain data is one technique (discussed later) that can be used to reduce this confusion.

Once the spectral classes have been assigned to information classes, the classification or model of landcover types must be tested for accuracy. A classification error occurs when a pixel is incorrectly labelled; in other words, its information class designation does not agree with the true class observed on the ground. Classification accuracy may often be best represented by a confusion matrix. The level of error typically present will depend on the nature of the cover types to be classified. For example, it is much more difficult to distinguish between spruce and hemlock forests than between coniferous forests and grasslands. The acceptable level of error will depend on the project requirements, and may not be the same for all classes. If an acceptable level of accuracy has been obtained at this point, further refinement of the classification using additional data planes may not be necessary. This is often the case when the study area has low topographic relief and/or the desired information requires no discrimination between cover types of similar spectral response patterns. Otherwise, it may be necessary to add additional dataplanes to the classification as outlined below (Eby 1987, Hart and others 1986).

CLASSIFICATION REFINEMENT USING ANCILLARY DATA

Often Landsat data alone are insufficient for constructing an adequate land cover model for a given area. This is especially true in areas having rugged terrain and for landcover types with similar reflectance values such as often occur in the Pacific Northwest and Rocky Mountain states. The addition of data planes containing topographic information can substantially reduce ambiguities (Hart and others 1986; Miller and Shasby n. d.; Strahler and others 1978; U. S. Geological Survey 1979). For example, coniferous forest types are generally very difficult to distinguish using only spectral data. However, many of these vegatation types have elevation, aspect, and slope requirements that can be used to distinguish one type from another within the Landsat classification. After stratification, the revised classification must be checked again for accuracy.

INTEGRATION OF THE CLASSIFICATION AND OTHER DATAPLANES

Once the classification is complete, it can be geometrically corrected to the standardized GIS map base. In this manner multiple dataplanes (roads, streams, elevation, precipitation, etc., as outlined earlier) can be queried simultaneously for any given region within the project area.

OUTPUT PRODUCTS

Output products may take many forms: disk or tape datasets, lineprinter maps, photographic products, plotter output for either vector or rastor data, or files downloaded onto diskettes for use with microcomputer-based systems. DIAL supports all of these output options.

CONCLUSIONS

Landsat-based landcover classifications integrated into a comprehensive Geographic Information System offer resource managers and scientists a powerful and cost-effective tool for providing answers to complex questions driven by management and research objectives. A Landsat-based GIS offers the additional advantages of easy information updating and the ability to answer multiple research and management questions without costly and time-consuming data replication. DIAL's service philosophy recognizes the advantage of agencies performing their own projects, and in the process developing skills for manipulating project databases in an ongoing operational mode. DIAL assists in the integration of the skills and capabilities available in the agency's staff with the expertise and computing facilities offered at Washington State University to guide the agency towards self sufficiency in Landsat and GIS project endeavors.

REFERENCES

Castleman, K. R. 1979. Digital image processing. Englewood Cliffs, NJ. Prentice-Hall, Inc. 429 p.

Eby, James R. 1987. Old growth coniferous forest mapping using MSS data and shadow modeling. Paper presented at: The DIAL Symposium, Pullman, WA. October 15-16, 1987.

Estes, John E.; Hajic, Earl J.; Tinney, Larry R. 1983. Fundamentals of image analysis: analysis of visible and thermal infrared data. In: Colwell, Robert H., ed. Manual of remote sensing, 2nd ed. Falls Church, VA. American Society of Photogrammetry. 2 volumes: 987-1124.

Fleming, M. D.; Berkebile, J. S.; Hoffer, R. M. 1975. Computeraided analysis of Landsat-1 MSS data: A comparison of three approaches, including a "modified clustering" approach. West Lafayette, IN: Purdue University. LARS information note 072475. 9 p.

Freden, Stanely C.; Gordon, Frederick, Jr. 1983. Landsat Satellites. In: Colwell, Robert H.; ed. Manual of remote sensing, 2nd ed. Falls Church, VA: American Society of Photogrammetry. 2 volumes: 517-570.

Gill, Steven J.; Hart, Judy A. 1984. Landsat classification for the anthropologist and archaeologist. Unpublished paper on file at: Digital Image Analysis Laboratory, Washington State University, Pullman, WA. 24 p.

Hart, Judy A.; Gill, Steven J.; Wherry, David B. 1986. Post classification stratification of Landsat data using a digital terrain model. Paper presented at: Fourth Pacific Northwest Conference on Digital Technologies, Boise, ID. January 29-31, 1986.

Hart, Judy A.; Wherry, David B. (eds.) 1984. VICAR/IBIS user reference manual. Pullman, WA. Washington State University Computing Service Center. 4 volumes.

Hoffer, R. M. 1979. Computer-aided analysis of remote sensor data--magic, mystery, of myth? In: Proceedings of remote sensing for natural resources, Sept. 10-14, 1979. Moscow, ID. University of Idaho. 156-179.

Miller, Wayne A.; Shasby, Mark B. [n. d.]Refining Landsat classification results using digital terrain data. Sioux Falls, SD. Technicolor Graphic Services, Inc.; EROS Data Center. 17 p.

Photogrammetric engineering and remote sensing. 51 (9):1197-1514. September, 1985.

Schowengerdt, Robert A. 1983. Techniques for image processing and classification in remote sensing. New York. Academic Press. 249 p.

Strahler, Alan H.; Logan, Thomas L.; Bryant, Nevin A. 1978. Improving forest cover classification accuracy from Landsat by incorporating topographic information. Preprint, Twelfth symposium on the remote sensing of environment, Manila, Philippines. 927-942.

U.S. Geological Survey, EROS Data Center. 1979. Final report for Arizona vegetation resource inventory (AVRI) demonstration project. (Draft) Sioux Falls, SD.

UNDERSTORY DEVELOPMENT IN *PSEUDOTSUGA* FORESTS: MULTIPLE PATHS OF SUCCESSION

Charles B. Halpern and Jerry F. Franklin

ABSTRACT: Vegetation changes after catastrophic disturbance commonly follow multiple pathways, reflecting variation in initial community composition, intensity of disturbance, or availability of propagules. In this paper we examine patterns of understory development during 21 yr of succession in logged and burned *Pseudotsuga* forests in the western Cascade Range, Oregon. We use detrended correspondence analysis ordination to assess the successional pathways of six forest communities exposed to a gradient in disturbance. We then use Euclidean distances between pre- and post-disturbance samples in ordination space to evaluate the resistance and resilience of communities. DCA ordination reveals multiple paths of succession characterized by 1) initially rapid floristic change away from pre-disturbance composition, followed by gradual return and 2) increasing compositional change with disturbance intensity. Community resistance and resilience reflect interactions between disturbance intensity and the life history traits of dominant residual and invading species.

INTRODUCTION

Catastrophic disturbances such as clearcut logging or wildfire profoundly influence the composition of vegetation. Species comprising a post-disturbance community derive from a variety of sources--wind dispersed seed, on-site or buried propagules, and resprouting survivors. Their ultimate contribution to the seral flora reflects a complex interaction of initial abundance, disturbance intensity, propagule availability, and chance. Thus, in ecosystems subject to large-scale, heterogeneous disturbance, succession commonly follows multiple pathways (e.g., Cattelino and others 1979, Noble and Slatyer 1980). Further, the ability of component species to resist disturbance determines the relative change in community composition; reestablishment from seed or vegetative propagules determines the rate and extent to which initial composition is restored.

In this paper, we examine the response of *Pseudotsuga* forest communities to clearcut logging and slash burning. The data presented derive from 22 yr of observation of permanent plots in the western Cascade Range of Oregon. We first describe how successional pathways vary with initial community composition and with disturbance intensity. We then discuss how these factors influence community resistance to disturbance and long-term recovery, or resilience.

STUDY AREA

The study area, Watershed 1 of the H. J. Andrews Experimental Forest, lies along the western slope of the central Cascade Range, 80 km east of Eugene, Oregon. Elevations range from 442-1013 m and slopes average 50-60%. Soils are derived from tuffs and breccias and are primarily loam textured, moderately stony, and porous (Dyrness 1969). The climate is maritime with mild, wet winters and warm, dry summers. Annual precipitation averages 2302 mm, yet only 6% falls from June to August. Average minimum temperatures range from -5.5°C in January to 11.9°C in August; average maxima range from 5.5°C in January to 23.3°C in July (Bierlmaier and McKee in press).

Vegetation on Watershed 1 (WS1) is representative of the *Tsuga heterophylla* zone (Franklin and Dyrness 1973). Prior to logging, forest canopies were dominated by mature and old-growth *Pseudotsuga menziesii* (125 and 300-500 years-of-age, respectively), with *Tsuga heterophylla* in a variety of age classes. Understory vegetation was composed of six plant communities arrayed along a gradient of available moisture (Table 1).

Table 1.--Characteristics of the six forest understory communities of Watershed 1. Communities are arranged in order of increasing available moisture

Plant Community	Topographic Position	Dominant Species
Corylus cornuta - *Gaultheria shallon*	ridgetops; S-facing, upper slopes	*Corylus cornuta*, *Acer circinatum*, *Berberis nervosa*
Rhododendron macrophyllum - *Gaultheria shallon*	ridgetops; mid-slope benches	*Rhododendron macrophyllum*, *Gaultheria shallon*
Acer circinatum - *Gaultheria shallon*	mid- to upper, S-facing slopes	*Acer circinatum*, *Gaultheria shallon*
Acer circinatum - *Berberis nervosa*	mid- to lower-slopes	*Acer circinatum*
Coptis laciniata	mid- to lower-slopes	*Tsuga heterophylla*
Polystichum munitum	bottom- and steep, N- to E-facing slopes; seeps	*Polystichum munitum*, *Acer circinatum*

Poster presented at the Symposium on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Charles B. Halpern is Post-doctoral Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR; Jerry F. Franklin is Professor, College of Forestry and Natural Resources, University of Washington, Seattle, WA.

METHODS

During 1962, prior to logging of WS1, 134 permanent plots (2 X 2 m) were established, sampled, and assigned to one of six understory communities (Table 1). Within each plot, visual estimates of projected canopy cover (%) were made for all species less than 6 m tall. WS1 was clearcut over a 4 yr period (fall 1962-summer 1966). After logging, plots were resampled (summer 1966), slash was burned (October 1966), and plots were assigned to soil disturbance classes:

1. Undisturbed. Soil surface similar to that of the original forest--little mixing of soil and litter and no evidence of fire.
2. Disturbed - Unburned. Litter removed or mixed with mineral soil, but no evidence of fire.
3. Lightly burned. Surface litter charred by fire.
4. Heavily burned. Surface litter entirely consumed by intense fire.

Post-burning remeasurements were annual for 7 yr and, thereafter, were generally biennial.

Successional pathways were examined by ordinating composite samples through time using DECORANA, a FORTRAN program for detrended correspondence analysis (DCA) (Hill 1979). Composites represent the average cover of each species within each 1) plant community, 2) soil disturbance class, or 3) combination of community and disturbance class for each sampling year. Within each ordination field (e.g., Fig. 1) points representing the same composite sample in successive years were connected sequentially to form successional trajectories.
Measures of community resistance to disturbance and long-term recovery, or resilience, were derived from Euclidean distances between composite samples in ordination space. Resistance was defined as inversely proportional to the maximum Euclidean distance between pre- (time 0) and post-disturbance (time x) composite samples. Resilience was defined as inversely proportional to the Euclidean distance between pre-disturbance and final samples (17 yr).

RESULTS AND DISCUSSION

Multiple Pathways

Plant Communities--Ordination of community samples through time reveals a series of distinct successional trajectories (Fig. 1). Communities are aligned initially along Axis 2, generally corresponding with the moisture gradient. Following disturbance, rapid floristic change away from initial composition is followed by slow, unidirectional return. In addition, successional trajectories remain aligned along the initial moisture gradient.

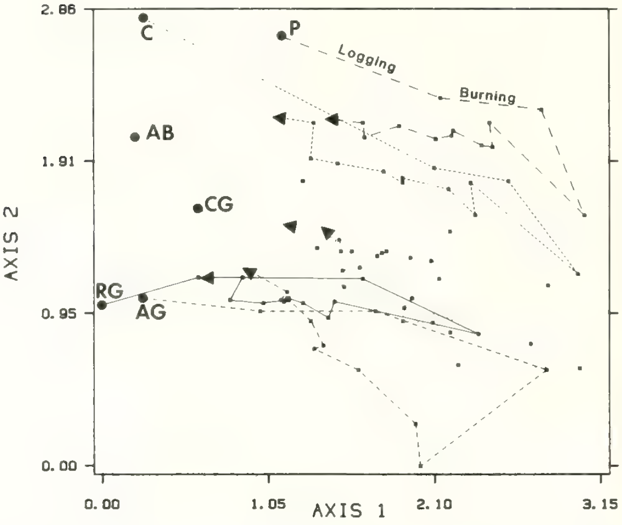

Figure 1.--DCA ordination through time of composite samples representing initial communities. Lines connect the same sample in subsequent years. Closed circles represent initial communities; second and third points represent post-logging and post-burning samples, respectively; arrows coincide with final samples (year 17) and indicate the direction of change through time. Community codes: CG = Corylus-Gaultheria, RG = Rhododendron-Gaultheria, AG = Acer-Gaultheria, AB = Acer-Berberis, C = Coptis, P = Polystichum.

Early post-disturbance patterns reflect the temporary loss of community dominants (e.g., Acer circinatum or Berberis nervosa) and the establishment of fugitive annuals (e.g., Senecio sylvaticus or Epilobium paniculatum). Subsequent compositional changes are less dramatic, reflecting gradual shifts in the abundance of rather persistent invading and residual species, with varying recovery to initial community composition (Halpern 1987).

Intensity of Soil Disturbance--The intensity of soil disturbance profoundly influenced the magnitude and direction of vegetation change. Ordinations through time of composite samples representing soil disturbance classes reveal increasing compositional change with disturbance intensity (Axis 1, Fig. 2). For example, composition on undisturbed sites (A, Fig. 2) changed relatively little after burning because initial dominants

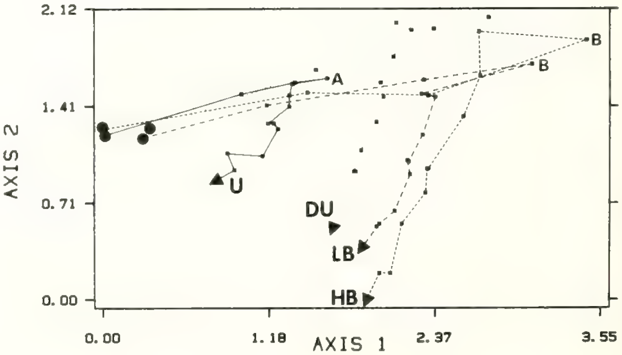

Figure 2.--DCA ordination through time of composite samples representing soil disturbance classes. A and B are referenced in the text. Disturbance codes: U = Undisturbed, DU = Disturbed-Unburned, LB = Lightly burned, HB = Heavily burned. See Figure 1 caption for details.

persisted. On lightly and heavily burned sites, in contrast, major changes in composition occurred; sample positions after 2 yr (B, Fig. 2), coincide with the maximum abundance of annual colonizers (e.g., *Senecio sylvaticus* and *Epilobium paniculatum*). Local prominence of these species reflected copious seed production, the interaction of a winter annual life cycle with fall burning, and an affinity for the high soil fertility associated with recent burns (West and Chilcote 1968).

Subsequently, composition changed gradually from herb- to shrub-dominated understories (Axis 2, Fig. 2). Differences in the distribution of residuals and invaders account for the increase in trajectory length with disturbance intensity. For example, undisturbed sites were reoccupied by resprouting dominants (e.g., *Acer circinatum*), whereas disturbed and burned sites were dominated by invading shrubs--*Rubus parviflorus* on disturbed-unburned sites and *Ceanothus velutinus* and *C. sanguineus* on lightly and heavily burned sites.

Interaction of Initial Composition and Disturbance Intensity--Multiple successional paths may reflect the combined influence of initial composition and disturbance intensity. For example, where soil was undisturbed, communities generally maintained their initial floristic character through time (Fig. 3A). Successional trajectories are variously directed, occupying small discrete zones within the ordination field. Distances encompassing each trajectory are consistently shorter than those separating them. Two trends account for these patterns: 1) invaders played a minor role on undisturbed sites and 2) original community dominants persisted through disturbance and generally recovered to initial abundance.

In contrast, where soil was lightly burned, communities changed profoundly in response to fire (Fig. 3B). Pre-disturbance samples are aligned along Axis 2, roughly coinciding with the moisture gradient. After burning, however, community trajectories briefly converge due to widespread establishment of invading annuals and temporary loss of forest residuals. Trajectories subsequently diverge as communities display distinct patterns of development (Halpern 1987). Additionally, recovery of original community composition is poorer on lightly burned (Fig. 3B) than on undisturbed sites (Fig. 3A), as indicated by distances separating initial and final samples.

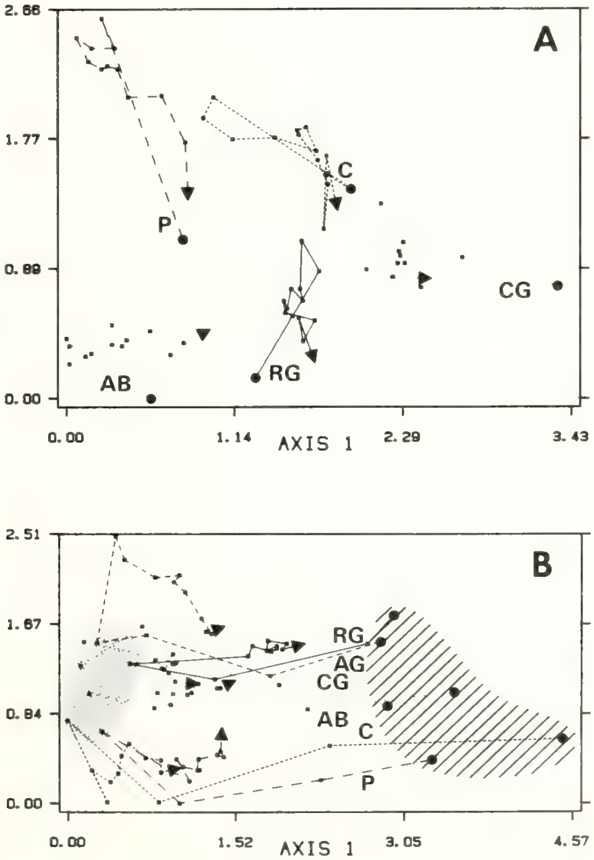

Figure 3.--DCA ordination through time of composite samples representing initial communities on A) undisturbed and B) lightly burned sites. Hatched and stippled areas illustrate convergence from initial (hatched) to post-burning (stippled) composition. See Figure 1 caption for details.

Measures of Resistance and Resilience

Resistance and resilience are measures of the immediate and long-term response of communities to disturbance, respectively. Resistance to disturbance reflects both the persistence of initial species' canopies and the exclusion of invaders. Community resilience derives from the recovery of initial dominants and the elimination of invaders.

Intensity of Disturbance--Both resistance and resilience varied inversely with the intensity of disturbance (Fig. 4). For example, undisturbed

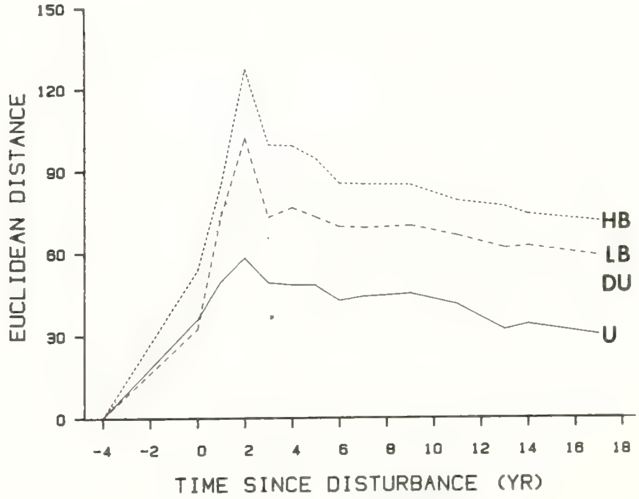

Figure 4.--Changes in Euclidean distance with time between pre- and post-disturbance composite samples representing soil disturbance classes. Times "-4", "0", and "1" represent initial forest, post-logging, and post-burning samples, respectively. See Figure 2 caption for disturbance class codes.

sites displayed high resistance (i.e., small maximum Euclidean distance) relative to disturbed and burned sites. In this system, loss of aboveground structures appears directly related to fire severity. The establishment of invading annuals is also directly related to disturbance intensity. For example, invaders such as Senecio sylvaticus may respond to the increased availability of germination sites and of soil nitrogen on burned sites (West and Chilcote 1968).

The resilience of undisturbed sites was also greatest (i.e., smallest Euclidean distance at final sampling). Understory recovery in Pseudotsuga forests typically depends on vegetative expansion of survivors, as reproduction from seed appears poor (Haeussler and Coates 1986; Russel 1974). Nevertheless, initial dominants recover more slowly on burned sites than on unburned sites (Haeussler and Coates 1986; Kraemer 1977; Steen 1966), despite an ability to sprout after severe fire. Furthermore, both the magnitude and duration of dominance of the principal invading shrubs, Ceanothus sanguineus and C. velutinus, increase with disturbance intensity. Because elevated temperatures stimulate germination of its buried seed, Ceanothus typically increases in abundance with burning intensity (references cited in Conard and others 1985). Its greater persistence on burned sites may reflect reduced competition from residual shrubs, as well as differences in its establishment.

Plant Communities--Plant communities generally were similar both in their resistance and resilience (Fig. 5). However, the contrast was greatest between Coptis and Polystichum communities. The Coptis type--associated with dense sub-canopies of Tsuga heterophylla--is extremely depauperate. Invading species dominated the post-disturbance flora and a paucity of residuals resulted in poor long-term recovery. In contrast, the Polystichum type is typically well-developed. Although invaders were briefly dominant, surviving residuals served as centers for vegetative expansion, promoting relatively rapid community recovery.

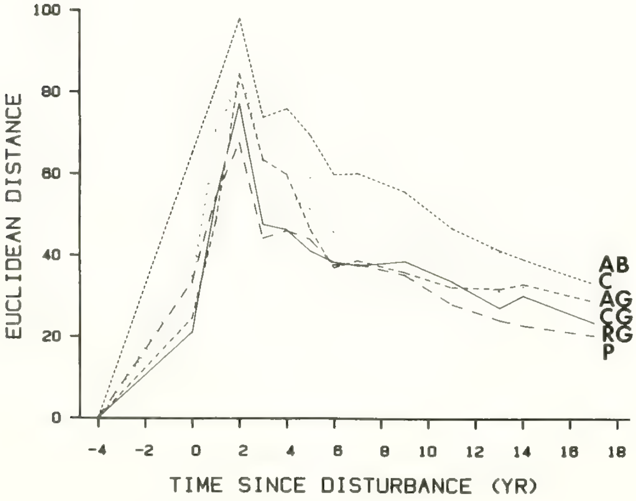

Figure 5.--Changes in Euclidean distance with time for the initial communities. See Figure 4 caption for details and Figure 1 caption for community codes.

Interaction of Initial Composition and Disturbance Intensity--Among disturbance classes, community responses varied dramatically. For example, on undisturbed sites, resistance of the depauperate Coptis community was intermediate and resilience was high (Fig. 6A). Surviving Tsuga heterophylla reestablished a dense understory tree canopy, largely preempting invaders. In contrast, resistance and resilience were relatively low for lightly burned Coptis sites (Fig. 6B). Seral communities were dominated by invaders and by initially uncommon residuals released from competition. Without a well-developed residual flora, long-term recovery after light burning may require canopy closure to eliminate these species. However, formation of a dense Tsuga heterophylla sub-canopy will be slower than on undisturbed sites, as reestablishment must be from seed.

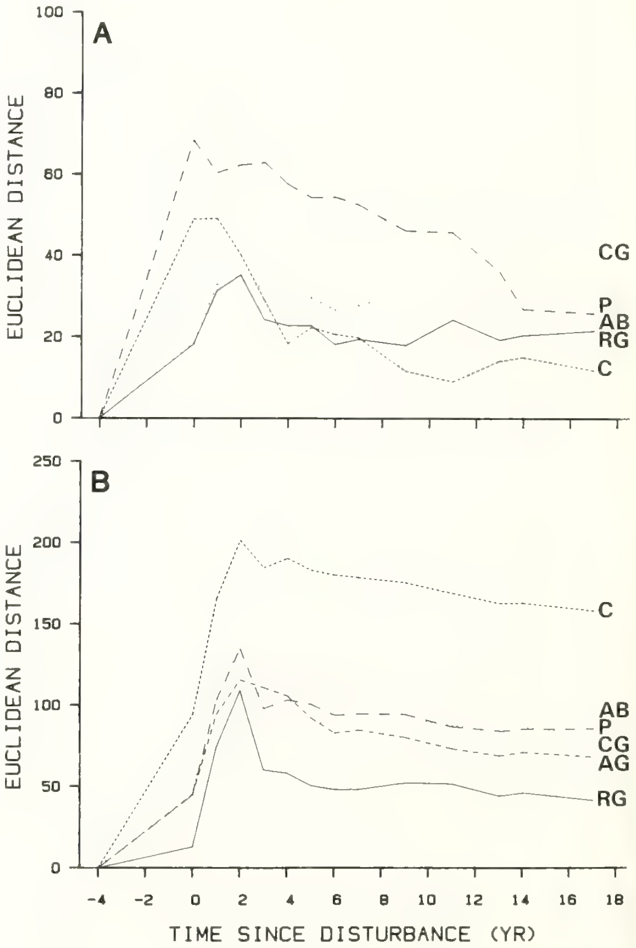

Figure 6.--Changes in Euclidean distance with time for the initial communities on A) undisturbed sites and B) lightly burned sites. See Figure 4 caption for details and Figure 1 caption for community codes.

CONCLUSIONS

Multiple Paths of Succession

Multiple paths of succession were observed after logging and burning of Pseudotsuga forests. Alternate pathways illustrate the importance of initial composition and disturbance intensity in understory development. Community trajectories were rather distinct, characterized by maintenance of the initial moisture gradient and by a gradual return toward initial composition. Alternate paths of succession also resulted from differences in disturbance intensity. The magnitude and direction of compositional change reflected variation in the response of dominant residual and invading species to a gradient in disturbance.

Community Resistance and Resilience

Within the range of disturbance intensities studied, Pseudotsuga communities exhibited an inherent tendency to return toward initial composition. Other authors have termed this trend stability (e.g., May 1973), adjustment stability (e.g., Sutherland 1981), or resilience (e.g., Westman 1978). Recovery from catastrophic disturbance in our system is founded in the moderate resistance of community dominants to logging and burning, and in their ability to subsequently perennate from subterranean structures.

Disturbance intensity largely determined the magnitude of compositional change and the degree of recovery. Initial composition and structure also influenced the resistance and resilience of communities (e.g., depauperate Coptis and well-developed Polystichum types). The interaction of disturbance intensity and initial composition further contributed to variation in the immediate and long-term response of communities to catastrophic disturbance.

REFERENCES

Bierlmaier, F.; McKee, A.(In press). Climatic summaries and documentation for the primary meteorological station at the H. J. Andrews Experimental Forest, Blue River, Oregon: 1972 through 1984. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

Cattelino, P. J.; Noble, I. R.; Slatyer, R. O.; Kessell, S. R. 1979. Predicting the multiple pathways of plant succession. Environmental Management. 3: 41-50.

Conard, S. G.; Jaramillo, A. E.; Cromack, K. Jr.; Rose, S., compilers. 1985. The role of the genus Ceanothus in western forest ecosystems: Report of the workshop; 1982 November 22-24; Corvallis, OR: Oregon State University. Gen. Tech. Rep. PNW-182. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 72 p.

Dyrness, C. T. 1969. Hydrologic properties of soils on three small watersheds in the western Cascades of Oregon. Res. Note PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Dyrness, C. T. 1973. Early stages of plant succession following logging and slash burning in the western Cascades of Oregon. Ecology. 54: 57-68.

Franklin, J. F.; Dyrness, C. T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Haeussler, S.; Coates, D. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: a literature review. British Columbia Ministry of Forests. Land Management Rep. No. 33. 180 p.

Halpern, C. B. 1987. Twenty-one years of secondary succession in Pseudotsuga forests of the western Cascade Range, Oregon. Corvallis, OR: Oregon State University. 239 p. Dissertation.

Hill, M. O. 1979. DECORANA--A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ecology and Systematics, Cornell University, Ithaca, NY. 52 p.

Kraemer, J. F. 1977. The long term effect of burning on plant succession. Corvallis, OR: Oregon State University. 123 p. Thesis.

May, R. M. 1973. Stability and complexity in model ecosystems. Princeton: Princeton University Press. 235 p.

Noble, I. R.; Slatyer, R. O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio. 43: 5-21.

Russel, D. W. 1974. The life history of vine maple on the H. J. Andrews Experimental Forest. Corvallis, OR: Oregon State University. 167 p. Thesis.

Steen, H. K. 1966. Vegetation following slash fires in one western Oregon locality. Northwest Science. 40: 113-120.

Sutherland, J. P. 1981. The fouling community at Beaufort, North Carolina: a study in stability. The American Naturalist. 118:499-519.

West, N. E.; Chilcote, W. W. 1968. Senecio sylvaticus in relation to Douglas-fir clearcut succession in the Oregon Coast Range. Ecology. 49: 1101-1107.

Westman, W. E. 1978. Measuring the inertia and resilience of ecosystems. BioScience. 28: 705-710.

RIPARIAN DOMINANCE TYPE CLASSIFICATION FOR MONTANA

Paul L. Hansen, Steve W. Chadde and Robert D. Pfister

INTRODUCTION

The Montana Riparian Association (MRA) is a cooperative sponsored by federal and state agencies, private organizations, and individuals, located at the University of Montana's School of Forestry. Chartered in June 1986, the first objective of the MRA was to complete a dominance type classification of the riparian plant communities in Montana. This work is being followed by the development of an ecological classification based on site potentials. Data collection and analysis for this second phase are currently under way.

METHODS

Field sampling was conducted in 1985 and 1986 for development of the dominance type classification. Communities were sampled to encompass a broad range of environments. The selection of sample stands was based on "subjective sampling without preconceived bias" as described in Mueller-Dombois and Ellenberg (1974). Plots 50 m^2 were used to sample homogeneous riparian communities. Dimensions of most plots were 5 m by 10 m, a shape shown to be effective in sampling many riparian communities of our region (Tuhy and Jensen 1982; Youngblood and others 1985; Hansen and others 1987a; Platts and others 1987). Narrow stringer communities, such as those confined to the immediate river edge, were sampled using 2.5 m by 20 m plots. Forested communities were sampled using 375 m^2 plots (Pfister and Arno 1980).

Within each plot, a complete species list was compiled and unidentified plants collected for later office identification. Estimates of canopy cover (Daubenmire 1959) for each species were made using the following cover classes:

T = 0-1%
1 = 1-5%
2 = 6-25%
3 = 26-50%
4 = 51-75%
5 = 76-95%
6 = 96-100%

Soil characteristics were described for each plot. Water regime for the site was estimated and described, with notes taken on water table depths and the occurrence of flooding.

Additional data collected for each sample plot included species composition of adjacent wetter and drier communities, aspect, slope, elevation, and community shape and size. Disturbances such as logging or grazing were noted and current management of the area was described, where possible. Intensity of wildlife use was estimated and ranked as low, moderate, or high.

A stepwise procedure was used to determine riparian dominance types. Unknown plant species were first identified and corrections made to field data sheets. Data sheets were then examined to determine dominant overstory species. Dominance was assigned to those species having at least 25 percent canopy cover in the tallest layer of the sampled community. For example, a community having 30 percent canopy coverage of *Populus deltoides* (a tree), and 80 percent canopy coverage of *Symphoricarpos occidentalis* (a shrub), would be considered to be dominated by *Populus deltoides*. If two or more species in the tallest layer had coverages greater than 25 percent, the species having the greatest cover was considered dominant. If cover values were equal, the species were considered codominant.

Next, field data from other riparian studies in Montana were analyzed to determine dominance types. Site data from these sources were also useful in describing the range of environments associated with each dominance type. In addition, a large body of literature was examined for information regarding the ecology and management of each dominance type. For common, widely distributed species, such as *Populus tremuloides,* a large amount of previous research was available for review. For uncommon species of limited distribution, such as *Carex leptalea,* few data were available.

This information was next assembled into a draft manual suitable for field testing and review by research and management personnel of various agencies and organizations throughout the state. To date, nearly 500 copies of the "Riparian Dominance Types of Montana" (Hansen and others 1987b) have been distributed. The revised, final version will be available in June 1988 as a Montana Forest and Conservation Experiment Station publication.

Poster presented at the Symposium Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Paul L. Hansen is Assistant Research Professor and Steve W. Chadde is Research Ecologist, Montana Riparian Association, School of Forestry, University of Montana, Missoula, MT; Robert D. Pfister is Director, Mission Oriented Research Program, School of Forestry, University of Montana, Missoula, MT.

RESULTS AND DISCUSSION

Following data analysis and literature review, 149 riparian dominance types were described. Twenty-three tree species, 29 shrubs, 61 graminoids, and 36 forb species were identified as dominating riparian environments in Montana.

For each dominant species, a line drawing and distinguishing characteristics were presented, followed by information on its environmental and geographic distribution throughout Montana. Plant species frequently associated with each dominance type were listed and commonly encountered soil types and moisture conditions described. Each species was also assigned a "wetland status" identifier based on a system developed by the U.S. Fish and Wildlife Service (Reed 1986). Management considerations, such as timber and forage productivity, wildlife values, hydrologic characteristics, fire susceptibility, and recreational suitability were discussed. The dominance type descriptions will help resource managers identify and properly manage riparian habitats in Montana.

However, it must be acknowledged that this is only a beginning. Although useful for immediate needs such as inventory, mapping, and broad-scale management, dominance types do not necessarily reflect the potential plant community of a site. A dominance type classification is based simply on the vegetation currently dominating a given unit of land ("cover type"). Classifications that identify potential natural vegetation, as influenced by site characteristics such as soils, precipitation, temperature, and elevation will be of greater value in developing specific recommended management practices. This work, producing an ecological site classification for the riparian areas of Montana, is currently under way by the MRA.

REFERENCES

Daubenmire, R. 1959. A canopy coverage method of vegetational analysis. Northwest Science. 33: 43-64.

Hansen, P. L.; Chadde, S. W.; Cooper, S. V.; Pfister, R.D. 1987a. Wetland plant communities of the northern range, Yellowstone National Park: Second year study report. Unpublished report submitted to National Park Service. 41 p.

Hansen, P. L.; Chadde, S. W.; Pfister, R. D. 1987b. Riparian dominance types of Montana. Montana Riparian Association, School of Forestry, University of Montana, Missoula, MT: Review draft. 358 p.

Mueller-Dombois, D; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Pfister, R. D.; Arno, S. F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26: 52-70.

Platts, W. S.; Armour, C.; Booth, G. D.; Bryant, M.; Bufford, J. L.; Cuplin, P.; Jensen, S.; Nelson, R. L.; Sedell, J. R.; Tuhy, J. S. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 177 p.

Reed, P. B., Jr. 1986. Wetland plants of the United States of America 1986. WELUT-86/W17.01. Fort Collins, CO: U. S. Fish and Wildlife Service, Western Energy and Land Use Team.

Tuhy J. S.; Jensen, S. 1982. Riparian classification for the Upper Salmon/Middle Fork Salmon Rivers, Idaho. Smithfield, UT: White Horse Associates. 200 p. Unpublished.

Youngblood, A. P.; Padgett, W. G.; Winward, A. H. 1985. Riparian community type classification of eastern Idaho-western Wyoming. R4-Ecology-85-01. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

RELATIONSHIP OF HABITAT TYPE AND RANGE SITE

M. Hironaka

One often hears that each land management agency uses a land classification system that is not compatible with classification schemes of other agencies. This is not so! The agencies do have a unified classification system! The apparent confusion lies with the difference with which the classification units are named as well as the units belonging to different levels in the same classification hierarchy. The range site, ecological site, and habitat type classifications are units from the same classification system. Let me explain.

The range site is a land classification unit based on the climax vegetation and a specific productivity level. An ecological site is synonymous with range site--both are identical, but one land management agency prefers to use range site and another prefers using the term "ecological site" for the same classification unit.

The habitat type is also a land classification unit and it is based on the climax vegetation as is the range site. Separation of one habitat type from another is based on difference in climax vegetation alone and not on difference in productivity level. Land areas that support or supported different climax vegetation belong to different habitat types (fig. 1).

All range sites supporting or capable of supporting the same climax vegetation belong to the same habitat type. Thus, several range sites, each supporting or capable of supporting fundamentally the same climax vegetation are members of the same habitat type (fig. 2). Moreover, each range site within a habitat type is different from another range site in the same habitat type because of difference in productivity capability, although still capable of supporting the same climax vegetation.

This makes the range site/ecological site a subdivision of a habitat type, which is a habitat type phase. In this case, the habitat type phase is based on productivity level. The range site/ecological site is likened to the habitat type phase based on productivity (fig. 3). Thus, the two classification units, habitat type and range site, are of the same classification system, but are units from different levels in the same classification hierarchy.

ARTRV/FEID Habitat Type Without Subdivision (Phase)

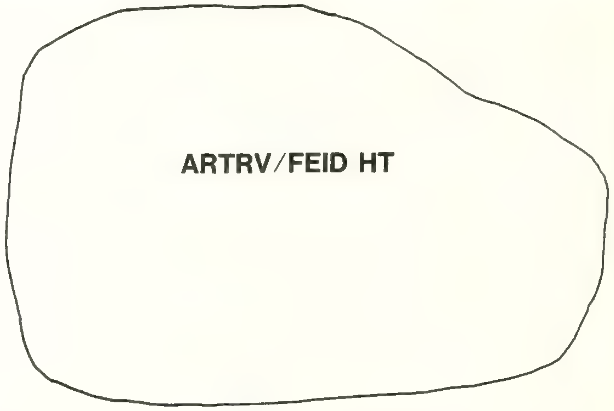

Figure 1--Habitat type is an area of land that supports or supported a specific climax vegetation (plant association). If the area has been disturbed, it is presumed that the area is yet capable of again supporting the same climax vegetation.

Range Sites: Each unit separated on basis of productivity level. All supporting the same plant association (ARTRV/FEID)

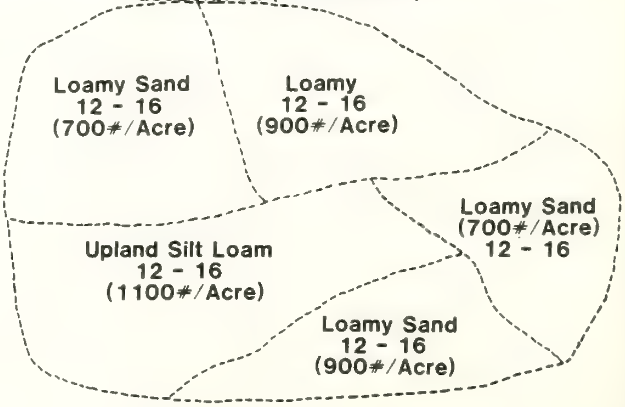

Figure 2--Range site is an area of land different from other areas in that it supports or supported a significantly different kind or amount of climax vegetation.

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M. Hironaka is Professor of Range Resources, University of Idaho, Moscow, ID.

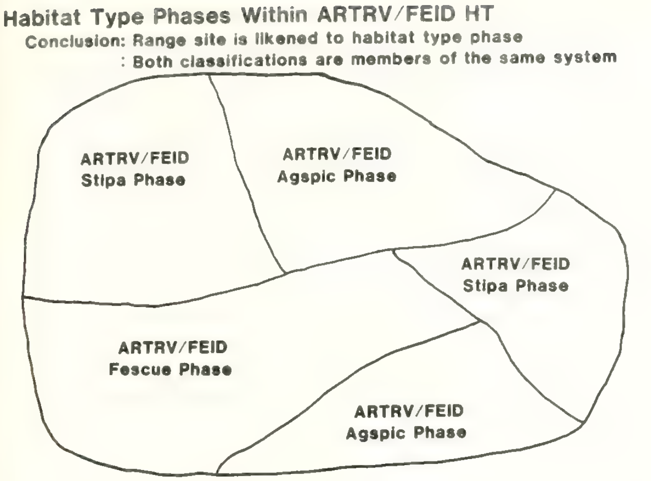
Habitat Type Phases Within ARTRV/FEID HT
Conclusion: Range site is likened to habitat type phase
: Both classifications are members of the same system
ARTRV/FEID Stipa Phase
ARTRV/FEID Agspic Phase
ARTRV/FEID Stipa Phase
ARTRV/FEID Fescue Phase
ARTRV/FEID Agspic Phase

Figure 3--Habitat type phase is a subdivision of a habitat type based on various expressions of the climax vegetation. When the subdivision is based on level of productivity (or soils) the habitat type phase is identical to range site.

Because each range site is associated with a specific group of soils, which in turn is associated with a specific habitat type, each habitat type also contains a unique set of soils. This fact establishes the relationship between soils and habitat type.

Once the relationship between the range site and associated soils has been established, wherever one of the associated soils series is located, the same range site exists. This same basic relationship also exists for the association of the unique set of soils to a specific habitat type.

Thus, each range site is associated with a unique set of soils. This also is the case with habitat type. This establishes the basic soil-vegetation relationship that has been sought by land managers. The relationship is between the climax vegetation and soils, not seral vegetation and soils. That is why the relationship only works with the climax vegetation of the range site and habitat type. It will not consistently work with seral community types, nor when soil classification is performed at the family level.

SOIL-HABITAT TYPE RELATIONSHIPS IN THE TROUT CREEK DRAINAGE, BOUNDARY COUNTY, IDAHO

Kent E. Houston, Maynard A. Fosberg, Kenneth E. Neiman, and Gary Ford

This study compared soil and habitat type classifications along a south-facing elevation gradient in the Selkirk Mountains of northern Idaho. Along this moisture-temperature gradient, the Inceptisol soil order is transitional to the Spodosol order. Corresponding to soil order changes, transitions occur between plant associations of the *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Abies lasiocarpa* series. The major objective of this poster is to illustrate the concomitance of soil and habitat type information in land classification and management.

STUDY AREA LOCATION AND DESCRIPTION

The study area is located in the Trout Creek drainage of the Selkirk Mountains 15 miles northwest of Bonners Ferry, ID (fig. 1 and fig. 2). Two contrasting geologic substrates occur in this portion of the Selkirks. These are steeply dipping Precambrian metasediments of the Belt Series along the eastern flank and granitics of the Kaniksu Batholith which make up the core of the range. Both substrates have been extensively modified by continental and alpine glaciation. A thin layer of volcanic ash from Mount Mazama (6,700 yrs. BP) Mount St. Helens (150 yrs. BP) forms a mantle over most of these glaciated surfaces.

The climatic regime of northern Idaho is an inland expression of the Pacific Coast maritime climate controlled by high-elevation westerly winds. This results in precipitation primarily in the spring, fall, and winter. Summers are warm and dry, with occasional thunder showers.

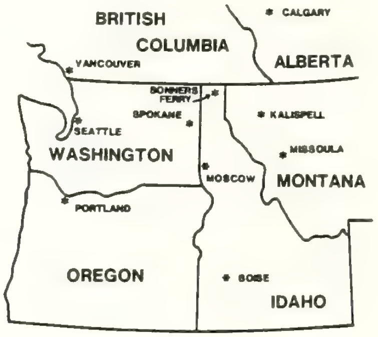

Figure 1--Study area is located 15 miles northwest of Bonners Ferry, ID.

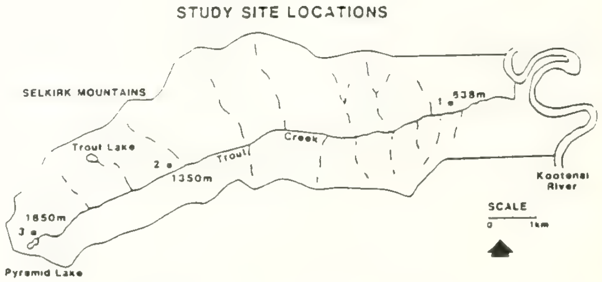

Figure 2--Study site locations along the Trout Creek drainage.

METHODS

Study sites within the Trout Creek drainage were subjectively selected to represent variation in soils and habitat types. Of 30 sites sampled, only three are discussed in this paper. Soils were classified to the family level. This classification was supported by existing laboratory data and soil climate data. Plant canopy cover was estimated for each species found within a 375 square meter plot encircling the soil pit. The climax vegetation or habitat type (h.t.) was identified to the phase level using Cooper and others (1987).

RESULTS AND DISCUSSION

Table 1 summarizes pertinent soil and habitat type characteristics of the following sites.

Poster presented at the Symposium "Land Classifications Based on Vegetation: Applications for Resource Management," Moscow, ID, November 17-19, 1987.

Kent E. Houston is Soil Scientist, Shoshone National Forest, Cody, WY; Maynard A. Fosberg is Professor of Soil Science, University of Idaho, Moscow, ID; Kenneth E. Neiman is Forest Ecologist, Resource Analysis and Management, Seattle, WA; Gary Ford is Soil Scientist, Idaho Panhandle National Forest, Coeur d'Alene, ID.

Site One

Site one is characterized by the Pseudotsuga menziesii/Physocarpus malvaceus h.t. Smilacina stellata phase. Associated soils are: Coarse loamy, mixed, frigid, Dystric Xerochrepts. The habitat type is indicative of a xeric (low summer precipitation) soil moisture regime and a frigid (cool) soil temperature regime.

Management implications include:

- Moderate timber productivity
- Possible significant reforestation problems
- Light to moderate seasonal cattle use
- Productive seral stages for big game food and cover requirements

Site Two

Site two is characterized by the Tsuga heterophylla/Clintonia uniflora h.t. Clintonia uniflora phase. Associated soils are: Medial over sandy-skeletal, mixed, Andic Cryochrepts. The habitat type is indicative of udic soil moisture regime (high summer precipitation) and cryic (cold) temperature regime. The presence of a volcanic ash layer (Bs horizons) leads to a higher moisture retention capacity in the surface soil.

Management implications include:

- High to very high timber productivity with excellent height growth for Pseudotsuga menziesii, Larix occidentalis, and Pinus monticola.
- High site productivity dependent on the amount of volcanic ash influencing the surface layer; if the surface soil is lost, productivity will decline due to infertile and droughty subsoils.

Site Three

Site three is characterized by the Abies lasiocarpa/Menziesia ferruginea h.t. Luzula hitchcockii phase. Associated soils are Medial over sandy-skeletal, mixed, Entic Cryorthods. The habitat type is indicative of a cryic temperature and udic moisture regime. The soil responding to the colder and wetter environment, have developed albic E (leached) horizons, Bh horizons (accumulations of organic matter), and spodic Bs horizons (accumulations of Fe and Al oxides).

Management implications include:

- Low timber productivity
- Forest regeneration and productivity limited by cold temperatures, high elevations, and short growing seasons
- Regeneration problems associated with high shrub coverage
- Site productivity depends upon the amount of volcanic ash influencing the surface layer; if the surface soil is lost, productivity will decline due to infertile and droughty subsoils

Table 1--Summary of site characteristics

Characteristic	Site 1	Site 2	Site 3
Elevation	638m	1350m	1850m
Habitat type & Phase	Psme/ Phma Smst	Tshe/ Clun Clun	Abla/ Mefe Luhi
Soil order	Incept.	Incept.	Spodosol
Soil moisture	Xeric	Udic	Udic
Soil temperature	Frigid	Cryic	Cryic
Diagnostic horizons	Ochric Cambic	Ochric Cambic	Albic Spodic
Horizonation sequence	0,Bw,C	0,Bs1, Bs2,IIC	0,E,Bh, Bs1,Bs2,
E and Bh development	None	Some-Weak	Strong
Ash influence	None	Strong	Strong
NaF pH	8.8	10.3	10.8
Substrate	Till Metasedimentary	Ash Till Granitic	Ash Till Granitic

CONCLUSIONS

The Trout Creek study illustrates that habitat types are a good method of extrapolating soil moisture and temperature regimes. Both of these characteristics are instrumental in the classification of soils to the family level.

The soil and habitat type relationship is naturally quite complex. This complexity requires soil scientists and plant ecologists to work together to optimize landscape delineation and to predict management responses. This would result in more useful and precise baseline data and classifications than if they were developed independent of each other.

REFERENCE

Cooper, S.V.; Neiman, K.E.; Steele, R.; Roberts, D.W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 135 p.

HABITAT TYPE CLASSIFICATION SYSTEM FOR NORTHERN WISCONSIN

John Kotar, Joseph Kovach, and Craig Locey

Although in the western United States the habitat type classification systems have been developed in almost every state and are now a common tool for evaluating biological potential of forest sites, the habitat type concept has not been used widely east of the Rockies. The only exceptions, to our knowledge, are the system developed for the Upper Peninsula of Michigan by Coffman and others (1983), and the system for northern Wisconsin presented here (Kotar and others, in press).

Perhaps the main reason few ecologists have attempted this type of vegetation classification in the east is the lack of readily perceived floristic differences, usually associated with strong elevation gradients and rugged topography. This certainly is the case in the Lake States. In addition, good examples of "old growth" forests are practically nonexistent.

Nevertheless, our work, as well as that of Coffman and his associates, showed that distinct associations can be recognized if reasonably mature stands (>50 years) are sampled across a range of sites and proper association analysis techniques are used. In Wisconsin and Michigan the different soils, associated with various types of glacial landforms, exert a strong influence on floristic composition of forest communities and provide a good basis for habitat type differentiation.

Our classification system for northern Wisconsin is based on relevé analysis of over 800 stands. We used the same sampling techniques as those commonly applied in many western studies, except that our plots were rectangular instead of circular. A 21x21 meter macroplot was divided into six subplots for estimating plant coverage. In order to simplify the use of identification keys and to allow for more specific local description of the habitat types, we divided northern Wisconsin into five regions (fig. 1).

Regional divisions were based on physiography, soils, climate, and certain floristic discontinuities. The natural boundaries between these regions could not be delineated precisely because soil, climate, and flora boundaries are almost always gradual, and they probably never coincide. Therefore, whole counties were grouped into regions in such a way that each region could be characterized by at least one major natural feature. A total of 17 habitat types and seven series were delineated for the five regions (table 1).

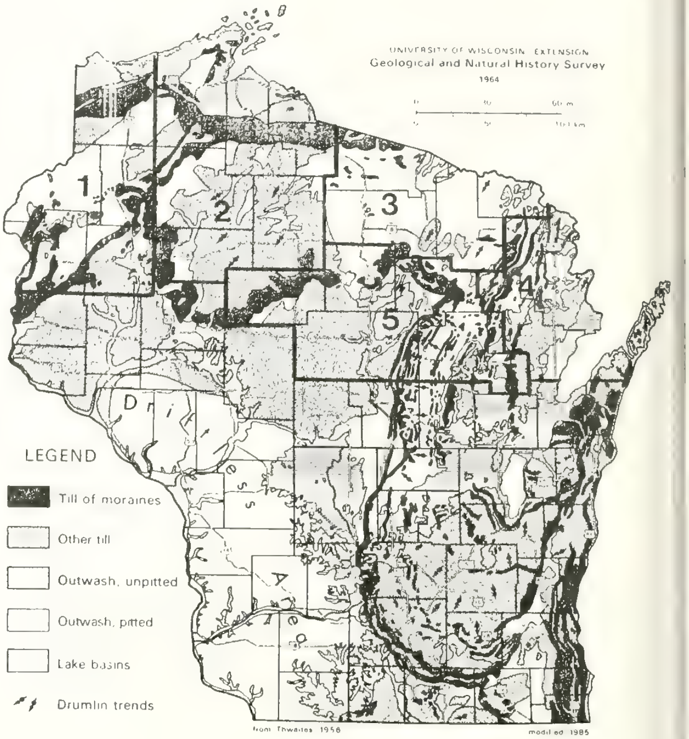

Figure 1--A map of glacial deposits of Wisconsin showing five regions delineated for present classification.

To further examine ecological relationships among various habitat types and their distribution along local environmental gradients, we subjected the relevés to a two-dimensional ordination using moisture and nutrient indices (synecological coordinates) developed by Bakuzis (1959). Bakuzis assigned each forest species a value of 1-5 to indicate the species' requirements for each of four site factors: moisture, nutrients, heat, and light. For example, a species with moisture index

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Poster presented at the symposium "Land Classifications Based on Vegetation: Applications for Resource Management," Moscow, ID, November 17-19, 1987.

John Kotar is Associate Research Scientist and Joseph Kovach is a Research Specialist in the Department of Forestry, University of Wisconsin-Madison. Craig Locey is Timber Management Specialist with the Wisconsin Department of Natural Resources.

Table 1--Forest habitat types of northern Wisconsin by series

Quercus ellipsoidalis series	
Quercus/Gaultheria-Ceanothus h.t.	QGCe
Quercus/Amorpha h.t.	QAp
Acer rubrum-Quercus rubra series	
Quercus-Acer/Epigaea h.t.	QAE
Acer-Quercus/Vaccinium h.t.	AQV
Pinus strobus series	
Pinus/Amphicarpa h.t.	PAm
Pinus/Maianthemum-Vaccinium h.t.	PMV
Acer saccharum-Tsuga canadensis series	
Acer-Tsuga/Dryopteris h.t.	ATD
Acer-Tsuga/Maianthemum h.t.	ATM
Acer saccharum-Fagus grandifolia series	
Acer-Fagus/Dryopteris h.t.	AFD
Acer saccharum series	
Acer/Vaccinium-Desmodium h.t.	AVDe
Acer/Vaccinium-Viburnum h.t.	AVVib
Acer-Quercus/Viburnum h.t.	AQVib
Acer/Atherium h.t.	AA
Acer/Viola-Osmorhiza h.t.	AViO
Acer/Hydrophyllum h.t.	AH
Acer/Caulophyllum-Circaea	ACaCi
Tsuga candensis series	
Tsuga/Maianthemum-Coptis h.t.	TMC

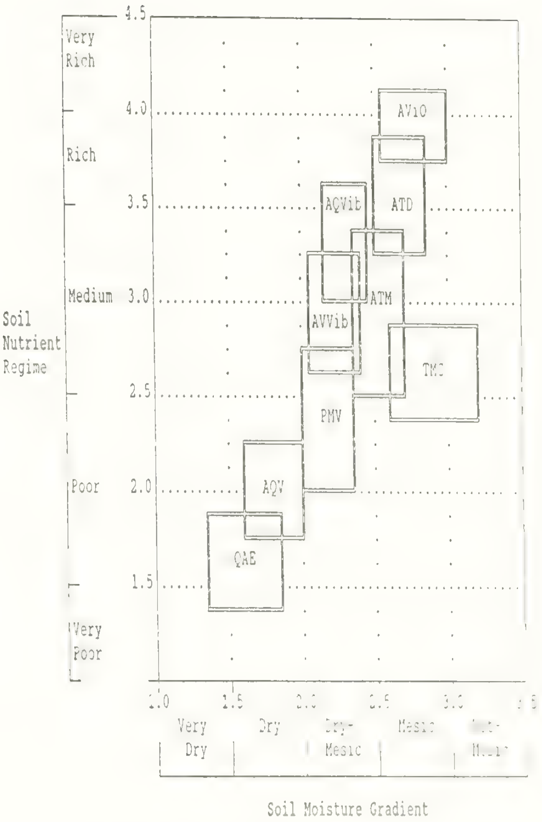

Figure 2--Relationship of nine habitat types of Region 3 to soil moisture and nutrient regimes.

of 5 occurs primarily in very wet environments. A species with a nutrient index of 1 occurs primarily on sterile, sandy soils. Bakuzis derived preliminary values for these indices from the literature and adjusted them through field measurements. An estimate of these environmental factors for a given site is obtained by calculating a mean index from the individual indices of all species present on that site.

We used the moisture and nutrient indices to calculate and plot the means for all relevés in our data set. The relevés, representing different habitat types, formed distinct clusters with some overlap among the most similar types. Figure 2 is a semi-quantitative representation of habitat type distribution on a moisture-nutrient grid for Region 3. The rectangles were drawn so that they enclose at least 90% of the relevés representing each habitat type. We arbitrarily assigned qualitative terms to segments of moisture and nutrient axes to provide better visual interpretation of the physical environment of various habitat types.

If all relevés representing the 17 habitat types that occur in the five regions are plotted on a single graph, considerable overlap among habitat types exists, as would be expected. This happens because many habitat types in one region may be considered as "ecological equivalents" of other types in other regions. These "ecological equivalents" occupy similar positions on the moisture-nutrient gradient in their respective regions, but their floristic composition differs sufficiently to be recognized as distinct associations.

In figure 3, the overall mean of the nutrient index is plotted against the soil moisture index for all habitat types. The habitat types in numbered clusters are ecological equivalents and overlap significantly if all relevés are plotted, but little or no overlap exists between the types in different clusters.

Although the habitat types in each cluster are different enough to require the development of individual management techniques, they can be treated as a unit for general planning purposes. For example, AH, ACaCi, and AViO habitat types in Cluster 1 represent the highest productivity sites for northern hardwoods in their respective regions. They all tend to be heavily dominated by sugar maple, but the importance of various associated species differs. On the other hand, AVDe and AVVib in Cluster 4 represent sites where the role of sugar maple is at its minimum. Although it is the most shade-tolerant tree, and is presumably capable of dominating at climax, the site conditions are not adequate for its optimal growth, and therefore, the succession proceeds much more slowly than it does on the previously mentioned types. Instead, early and mid-successional stages tend to be dominated by red oak and red maple, and are relatively stable.

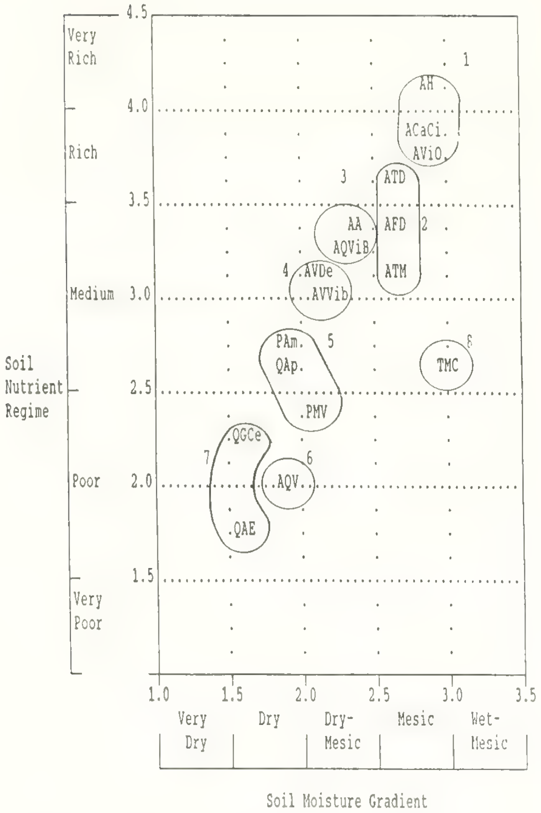

Figure 3--Relationship of all habitat types of northern Wisconsin to soil moisture and nutrient regimes. Numbered clusters are habitat type groups with similar management implications.

A field guide to this classification system has been completed and will be published in early 1988. It will contain the following information: identification keys; descriptions of important habitat type characteristics; successional diagrams; and a discussion of management implications for each type. Color illustrations of plants needed to identify the types will also be included.

The Field Guide can be obtained through the Department of Forestry, University of Wisconsin, Madison, 1630 Linden Drive, Madison, WI 53706. Cost $44 (includes postage and handling).

REFERENCES

Bakuzis, Egolfs V. 1959. Synecological coordinates in forest classification and in reproduction studies. St. Paul, MN: University of Minnesota. 244 p. Dissertation.

Coffman, Michael S.; Alyanak, Edward; Kotar, John; Ferris, James. 1983. Field guide to habitat type classification system for Upper Peninsula of Michigan and northeastern Wisconsin. Published by School of Forestry and Wood Products, Michigan Technological University, Houghton, MI. 160 p.

Kotar, John; Kovach, Joseph; Locey, Craig. 1988. Field guide to forest habitat types of northern Wisconsin. Published by the Department of Forestry, University of Wisconsin-Madison, and Wisconsin Department of Natural Resources. 212 p.

THE VEGETATION CLASSIFICATION AND DATABASE

OF THE MONTANA NATURAL HERITAGE PROGRAM

Andrew M. Kratz

The Montana Natural Heritage Program (MTNHP) was established by the State of Montana and The Nature Conservancy in 1985 to create a comprehensive statewide database on Montana's biological diversity. MTNHP is working on information acquisition, storage, and retrieval for data relating to the flora, fauna, and natural plant communities of Montana. Information on the existence, location, numbers, condition and status of rare and endangered plants, animals, and natural vegetation is collected and made available to all interested parties. MTNHP is one of nearly 50 Heritage Programs in the United States.

One of the program's tasks has been to assemble a comprehensive list of Montana's climax and seral natural vegetation types (plant associations, plant communities). The list of types has been arranged in the classification hierarchy developed by the United Nations Educational, Scientific, and Cultural Organization for the vegetation of the world. This framework separates forests from shrublands and herbaceous vegetation, then further subdivides each class into subclasses, groups, and formations. Below the formation level, MTNHP has listed series and then associations. This structure enables the MTNHP vegetation classification to be integrated with classifications developed by other Heritage Programs, and facilitates the exchange of information between states.

The MTNHP vegetation classification was developed through an extensive review of published and unpublished sources, including papers on habitat typing, journal articles, theses, and dissertations, as well as other "gray literature" such as private industry reports for environmental impact statements. These various papers describe vegetation for specific areas within the state, but the classification and database developed by MTNHP link these many separate sources to provide a statewide perspective.

The database includes information for each vegetation type on its distribution within Montana and site characteristics (slope, elevation, aspect, and soil). It also has comments on phases and successional relationships, as well as citations for the literature describing each type.

There are several useful aspects of the classification and database. They provide a foundation for the development of a comprehensive statewide guide to the vegetation of Montana. They enable Heritage Program staff to focus information collection activities on the most poorly described or threatened vegetation types in the state. They facilitate information exchange between states with similar types of vegetation. Coupled with MTNHP's site location database, they can provide information to public land managers and the private sector on the location and ecological status of Montana's most threatened vegetation types, thereby facilitating better management of these valuable resources.

The vegetation classification and database are dynamic. They will be amended or supplemented as more information on Montana's natural vegetation becomes available.

Poster presented at the symposium "Land Classifications Based on Vegetation: Applications for Resource Management," Moscow, ID, November 17-19, 1987.

Andrew M. Kratz is Ecologist/Research Specialist, Montana Natural Heritage Program, Helena, MT.

MAPPING AND APPLICATION OF PLANT ASSOCIATIONS FOR FOREST PLANNING:

TONGASS NATIONAL FOREST, ALASKA

Jon R. Martin and Thomas DeMeo

THE TONGASS NATIONAL FOREST

The Tongass National Forest is located in the Alexander Archipelago, southeastern Alaska. It is the largest National Forest in the United States, extending over more than 16.8 million acres. The forest encompasses an area 400 miles long and 100 miles wide and has a total coastline in excess of 11,000 miles.

Southeastern Alaska has a cool and moist maritime climate. Precipitation ranges from a recorded low in Skagway of 26 inches to a high in Little Port Walter of 211 inches per year. On the average, cloudy skies occur on 275 days per year. Average maximum temperature during the growing season range from 54 to 65 °F. Soil drainage, temperature variation along elevational gradients and soil disturbance caused by flooding, windthrow, and mass wasting are the dominant factors influencing the vegetation within southeastern Alaska. Fire is not an important factor and most of the forested land is in an old growth, climax condition.

THE PLANT ASSOCIATION PROJECT

The plant association (PA) classification work began as a pilot project in 1981 in northern southeastern Alaska. Since that time, about 3,000 forest stands have been sampled throughout southeastern Alaska. Seven series (Tsuga heterophylla, Tsuga heterophylla-Chamaecyparis nootkatensis, Tsuga heterophylla-Thuja plicata, Picea sitchensis, Tsuga mertensiana, Pinus contorta, and Mixed Conifer) and 45 forest PA have been described. We estimate that an additional 10 to 20 forest PA will be described.

A draft classification for the northern portion of southeastern Alaska was produced in 1985. Draft classifications for the central and southern portions will be printed in May of 1988. Final publications for these three areas should be published in 1988 and 1989. Currently there are four forest ecologists working full time and three soil scientists working part-time on the project.

Future efforts will focus on the classification of riparian and non-forest plant communities and implementation of existing forest PA classifications.

MAPPING PLANT ASSOCIATIONS

PA are mapped in conjunction with a soil and geomorphology mapping project. Mapping criteria were established to delineate as many vegetative attributes as practicable considering map scale constraints and management needs. Mapped units range in size from 20 acres to several hundred. Several similar PA may occur in any particular mapping unit. This will depend on the size and homogeneity of the vegetation and site within the mapping unit.

Field mapping was done on 4 inch/mile color aerial photographs. Field map verification and data collection were done by teams consisting of a soil scientist and plant ecologist prior to producing the final maps.

Mapped photo lines are digitized for use in a geographic information system (GIS). The GIS provides the capability to easily display the distribution and abundance of PA at a stand or watershed scale.

USING PLANT ASSOCIATIONS IN THE TONGASS FOREST PLAN

PA provide a useful descriptive and predictive management tool for silviculture and fish and wildlife habitat management. PA in the first revision of the Tongass National Forest plan will be used to describe the vegetative characteristics of fish and wildlife habitat in the climax, old-growth condition. Since most of the forest land in the Tongass National Forest is in this condition, PA can readily be used to estimate current habitat capability. PA are particularly valuable for describing the quality and quantity of forage in the understory of climax, old-growth stands. They are also useful for characterizing hiding/thermal cover properties for deer winter

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Poster presented at the Symposium, Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Jon R. Martin is Wildlife Biologist/Forest Ecologist, U.S. Department of Agriculture, Forest Service, Sitka, AK; Thomas DeMeo is Forest Ecologist, U.S. Department of Agriculture, Forest Service, Ketchikan, AK.

habitat, snag quality and quantity for cavity dependent species, and for describing large organic debris input potential along forest fish streams.

As we improve our understanding of successional patterns over the landscape, the usefulness of PA as a predictive tool for fish and wildlife habitat will increase. This will provide a basis for modeling changes in animal communities over time resulting from past and future changes in the vegetation mosaic.

PA with soils, landforms, and channel types were combined to develop a hierarchial classification of the streamside riparian ecosystem on the Tongass National Forest. Since PA reflect the characteristics of the environment, they provide a useful means of describing the riparian ecosystem. Management of this ecosystem is becoming increasingly more complex due to the high resource values and the increased public awareness. Consequently, land managers need a more complete understanding of this ecosystem than was previously demanded. To accomplish this, the riparian ecosystem must first be described and inventoried. The approach just described will be used in the Forest Plan revision to inventory the riparian ecosystem.

The PA map on the GIS will provide an inventory of sites with silviculture problems or opportunities. Standards, guidelines, and prescriptions for management of many different sites will be written by PA. Regeneration problems due to flooding, shrub competition, poorly drained soils, and short growing seasons at high elevations can be evaluated. Estimates of timber productivity by species can be made. This information will provide the data needed to develop site specific land management prescriptions and to estimate management costs.

GIX: A PC-BASED GEOGRAPHIC INFORMATION SYSTEM (GIS)

Toru Otawa

ABSTRACT: A raster-based geographic information system named GIX is being developed for personal computers. This paper summarizes its design philosophy and highlights system capabilities. It also includes a case study demonstrating the application of GIX to preliminary habitat type modeling.

INTRODUCTION

Many GIS systems were developed in the early 1980's in response to the introduction and promulgation of relatively inexpensive personal computers. However, most of them used the same level of software technologies as ones developed on mainframes and mini-computers and did not really take advantage of the potential of personal computers in many respects as will be discussed later. To improve upon the existing PC-based GIS, a new generation of software is being developed by the author.

GIX is a family of software routines primarily designed for the IBM(tm)-PC, PC-XT, PC-AT, PS/2 and their compatibles running under MS-DOS(tm), and is written mostly in the ANSI-standard C language. The underlying philosophy of this endeavor is to develop a user-friendly, low-cost system and yet powerful enough to be able to use in professional projects. Some of the advantages of GIX include the following: (a) extremely user-friendly (b) low capital outlay (c) many analysis capabilities comparable to large, expensive systems, (d) data compatibility with many mainframe and mini-based systems, and (e) easy transportability to other operating systems such as UNIX(tm) and OS/2(tm).

MAJOR SYSTEM FEATURES UNIQUE TO GIX

Error Handling and User-Friendliness

One of the major drawbacks of the existing PC-based GIX routines is that they do not handle user input errors correctly in many cases. In other words, if a user enters a wrong command or a set of data, then his/her program might lead to system halt. Author's preliminary investigation shows that only a few among many PC-based GIS systems receive high rating in this regard. GIX was designed so it accepts only the type of entry that its particular routine is anticipating from a user. If the user enters a wrong data type, then it prompts to the correct type of entry or terminates the user's program. Or, where appropriate, pop-up menus are used to reduce possible user errors.

Internal Data Type

Many PC-based GIS such as pMAP and CRIES use 2-byte integer data. The fact that they cannot handle floating point data poses a serious problem for users in the scientific community. In other words, on these systems 1.4 plus 1.4 becomes 2, for example, because of truncation. To avoid such inconveniences, GIX uses the double-precision data type (i.e., 8-byte) for its internal data structure. Conversely, however, this approach has some limitations in that the speed of data input-output could be reduced and additional data storage might be required because of the inherent nature of this data type.

Data Compatability

There are basically two data format types in GIX: GDF and DBF. The former is a file type for individual data layers, for example, soils and vegetation types, while the latter is provided for dBASE III (tm) compatibility. Once all the data layers are prepared the user can pack them into the DBF type. One file can contain as many as 128 data layers or fields. Users of dBASE III or clones can perform very complex analyses using this file. In particular its relational capability could be fully utilized, if more than 128 fields are to be analyzed.

The GDF files can be created either from digitizing or from downloading existing data on mainframe or mini-based GIS such as MOSS, COMARC, ERDAS and ARC/INFO. The main requirement for the latter is there should be an export utility routine converting binary to the ASCII format on the host side. GIX has several data import routines to modify a variety of data formats for its use.

Query Capability

Using the aforementioned DBF file the user can perform very complex query on the data base using logical combinations--AND, OR and NOT. Its results can be quickly shown directly on screen with the system's graphic display program. Very few raster-based GIS have this capability at this point in time.

Poster presented at the conference on Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID, November 17-19, 1987.

Toru Otawa is Assistant Professor of Landscape Architecture and Co-director of GIS Laboratory/College of Art and Architecture, University of Idaho, Moscow, ID.

USES IN RESOURCE PLANNING AND MANAGEMENT

GIX enables resource managers to analyze in an objective manner primary data layers (e.g., soils, habitat types, cover types, and geology) in small-scale land management and planning. A number of "guesstimate" situations could be eliminated with GIX thanks to the data which provide planners with accurate information on resource distribution patterns. Actual tasks of land managers would then shift from mechanical work (e.g., drafting and shuffling of maps) to data management and interpretations.

GIX could also be used for the detailed assessment of environmental impacts for timber, range, recreation, and mining, once the existing resource data are converted into digital format. Another application may be to aid in the development of mapping unit design for soil and habitat type mapping by using its basic topographic programs for slopes, aspects, elevation and solar radiation index. In addition, its query capability could be applied to vegetation modeling and a number of other tasks that land managers routinely perform.

To demonstrate the applicability of GIX four data layers were digitized from the Idaho Panhandle National Forests: elevation, soils, vegetation types, and grizzly bear habitat types. Slope and aspect files were then directly computed from the elevation file using SLOPE and ASPECT routines in GIX. This area encompasses 4 square miles (i.e., 2 x 2 miles) (fig. 1). Once their editing was complete, they were packed into a DBF file. Then geo-query module in GIX was applied to conduct preliminary examination of the ALBA/VASC habitat type using the following demonstration criteria: elevation >= 6000 feet, slope >= 20%, and aspect between 45 and 315 degrees (fig. 2). With 160 x 160 data cells it required approximately 3 minutes for this task on an 8mhz IBM(tm) PC-AT with an 80287 and 640KB of RAM.

CONCLUSIONS

GIX provides resource managers with an excellent tool for geographic data analyses. In particular, in addition to many analytical capabilities it has a unique query and database management capability which is not present in most of the raster-based GIS for personal computers. Because of its user-friendly environment, it is also a good tool for training and education. Above all its cost performance can really be appreciated once it is applied to a small-scale land planning and management project.

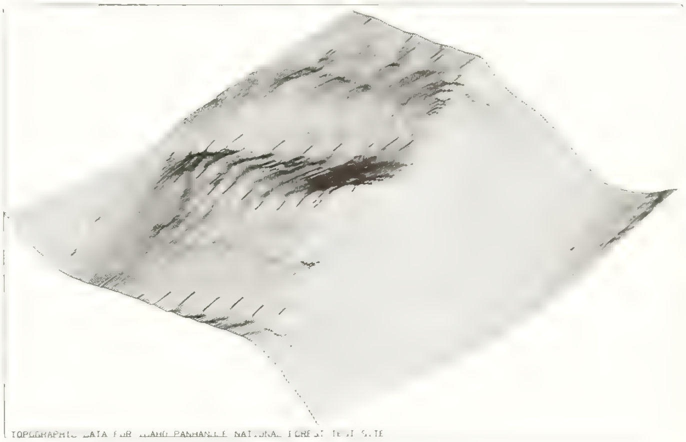
TOPOGRAPHIC DATA FOR IDAHO PANHANDLE NATIONAL FOREST TEST SITE

Figure 1--Aerial view of study site.

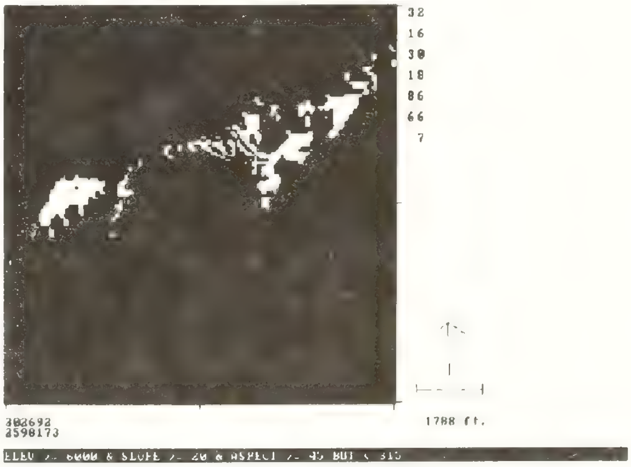

Figure 2--Preliminary assessment of ABLA/VASC habitat type using geo-query module. White areas satisfy criteria applied.

REFORESTING FLOOD-PLAIN SITES IN INTERIOR ALASKA

Andrew P. Youngblood and M. Joan Foote

ABSTRACT: Regeneration research on the flood plain of a major river in interior Alaska is designed to examine the effect of silvicultural system and site preparation, and to determine the effect of vegetation type, on natural and artificial regeneration of white spruce. Preliminary results suggest the need to refine silvicultural prescriptions by vegetation type.

INTRODUCTION

Flood plains along major rivers in interior Alaska support productive forests of white spruce (Picea glauca (Moench) Voss) and associated hardwoods. Historically, these forests were exploited for cordwood during the gold rush and settlement period of the early 1900's, when large steam-powered sternwheelers delivered supplies and equipment to mining operations. With establishment of the Tanana Valley State Forest in 1983, the Alaska State Division of Forestry has increased utilization of these forests. Flood-plain forests of white spruce present unique challenges for timber management because of apparent changes in site productivity as soil temperatures decrease (Dyrness and others, in prep.), seasonal access, ineffective silvicultural techniques for slash disposal and site preparation, cyclic seed production, and the rapid regrowth of competing vegetation. Forest managers in interior Alaska lack sufficient information on the best methods for regenerating white spruce.

This paper reports preliminary results of regeneration research conducted on three typical flood-plain vegetation types. Objectives were to assess the effects of various silvicultural systems and practices and determine the effect of vegetation type on artificial and natural regeneration of white spruce.

METHODS

The study area is located on Willow Island, a 210 hectare (520 ac.) island in the Tanana River about 32 kilometers (20 mi.) southwest of Fairbanks, Alaska (lat. 64°50'N, long. 148°0'W). Previous work (Foote 1983; Viereck and others 1984) indicated both stand structure and species composition of stands on Willow Island were typical of flood-plain forests along the lower Tanana River. Thirteen broadly defined plant communities have been recognized (Dyrness and others, in prep.), ranging from herbaceous communities in abandoned sloughs to multi-aged stands of white and black spruce (Picea mariana (Mill.) B.S.P.). Three communities dominated by mature white spruce (hereafter referred to as sites) were selected to receive different combinations of silvicultural treatments. Pretreatment species composition, stand structure, and soil attributes are summarized in table 1.

Seven shelterwood and seven clearcut blocks, totaling 22 and 34 hectares (54 and 85 ac.) respectively, were whole-tree logged in January and February, 1983. Zasada and others (1987) described snow conditions and winter logging techniques. Five of the seven shelterwood blocks contained about 100 residual stems per hectare (40 stems per ac.) following logging; this logging treatment is referred to as SW-1. A lower density of stems was retained in the two remaining shelterwood blocks (SW-2). These two blocks may resemble a seedtree cut with only 50 residual stems per hectare (20 stems per ac.). Site I contained a single clearcut block, Site II contained eight blocks (three clearcut, three SW-1, and two SW-2), and Site III contained five blocks (three clearcut and two SW-1).

Mechanical scarification, using a dozer blade or pulled Bracke-type patch scarifier, was applied to 30 by 60 meter (100 by 200 ft.) plots in all but two cutting blocks during the summer of 1983. An adjacent plot of equal size received no scarification, and served as a control. Thirteen hectares (32 ac.) in two clearcuts not receiving mechanical scarification on Site I and III were broadcast burned in July, 1983 (Zasada and Norum 1986).

Each site preparation plot was split to receive one of three artificial regeneration treatments; planted seedlings, protected seeds, or unprotected seeds. Putman and Zasada (1986) have previously detailed techniques for protecting seed from adverse environmental stresses using plastic cone and funnel shelters. Nursery-reared containerized white spruce seedlings (1-0 stock, seed source Willow Island) were planted on a 2.4 by 2.4 meter (8 by 8 ft.) spacing in June, 1983. At the same time, about 8 to 10 uncoated white spruce seeds

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Andrew P. Youngblood is Research Forester and M. Joan Foote is Botanist, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Fairbanks, AK.

Table 1--Species composition, stand structure, and soil parameters for three sites on Willow Island, Alaska

	Site I	Site II	Site III
Vegetation (percent cover)			
Picea glauca		20 - 50	30 - 60
P. glauca and *P. mariana*	15 - 25		
Betula papyrifera	5 - 15		
Alnus crispa		10 - 60	< 5
Alnus tenuifolia		1 - 50	20 - 80
Rosa acicularis	10	10 - 25	5 - 20
Ledum groenlandicum	30		
Linnaea borealis	5	15	20 - 40
Vaccinium vitis-idaea	50	10 - 50	0 - 15
Equisetum arvense	15 - 40	2 - 40	0 - 20
Hylocomium splendens	40	20 - 70	60 - 90
Pleurozium schreberi	20	< 5	
Rhytidiadelphus triquetris		0 - 30	
Other Mosses	15	20	5
Peltigera aphthosa	5 - 25		
Stand Structure			
Tree ages (yrs.)	130 - 250	130 - 350	110 - 150
Average stand diameter (cm)	15 - 16	20 - 40	25 - 35
Basal area (m^2/ha)	13	27 - 38	19 - 31
Volume (bdft./ac.)[1]	9,000	12,000	14,000
Density (stems/ha)	500 - 600	300 - 800	250 - 550
Site Index$_{(100)}$	< 50	70 - 90	80 - 90
Soil Characteristics			
Litter/decomposing moss (cm)	15 - 25	5 - 23	0 - 16
Humus (cm)	0 - 1	0 - 3	0 - 3
Silty to sandy loam (cm)	> 37	35 - 60	25 - 80
Drainage	Poorly drained	Well-drained	Well-drained
Particle size	Silt loam over loamy sand	Silt loam over sandy loam	Silt loam over sandy loam
Permafrost[2] (cm)	37 - 70	Intermittent	Free

[1] Scribner Dec. C.
[2] Depth of seasonally active thaw zone.

(same seed source) were direct seeded on "seed-spots". Seed-spots on an unscarified site preparation plot (controls) were protected by small plastic funnels, while seed-spots on scarified plots were protected by plastic cones. Finally, seed was sown on seed-spots lacking protection. From each site preparation plot fifty seedlings or seed-spots from each regeneration treatment were randomly selected for monitoring successful artificial regeneration.

Natural regeneration was monitored on twenty 4 meter squared (30 ft.^{2}) plots receiving patch scarification or broadcast burning on all three sites.

Establishment (survival) and third-year height growth increment were recorded in 1987 for 4800 planted and direct seeded seedlings. Analysis of variance using percent survival with an arcsine transformation and third-year height growth increment as single dependent variables was used to test for significant differences between logging method-site preparation-regeneration method treatment combinations. Sites were considered unreplicated experimental units with separate analyses conducted for each site.

RESULTS

Natural regeneration of white spruce was sporadic on Willow Island following logging. Broadcast-burned blocks contained more seedlings established after 1983 than advanced regeneration, and apparently provided the best seedbed for germination and establishment of natural seedlings.

Percent survival of artificial regeneration is summarized in table 2. Preliminary analysis indicated little difference between cutting methods (clearcut, shelterwood-1, and shelterwood-2 on Site II, $F = 3.85$, $p < 0.097$; or clearcut and shelterwood-1 on site III, $F = 28.01$, $p < 0.034$). Both site preparation and regeneration method affected survival; survival of planted seedlings after three years was generally

Table 2--Percent survival of artificial regeneration after three years, by logging method, site preparation, and regeneration method, for three sites on Willow Island, Alaska. N represents the number of regeneration plots, each containing fifty seedlings or seed-spots. SE is the standard error of the estimated mean

	Site I			Site II			Site III		
Treatment	Percent survival	N	SE	Percent survival	N	SE	Percent survival	N	SE
CC[1] BL[2] PL[3]	97.8	4	4.79	96.4	3	5.15	97.1	2	5.29
CC BL SP	62.0	4	4.79	43.8	3	5.16	55.3	2	5.29
CC BL SU	31.7	4	4.79	71.5	3	5.16	47.0	2	5.29
CC PA PL	98.2	4	4.79	98.3	3	5.16	97.9	2	5.29
CC PA SP	56.4	4	4.79	63.2	3	5.16	73.1	2	5.29
CC PA SU	30.9	4	4.79	74.9	3	5.16	36.0	2	5.29
CC NS PL	99.6	4	4.79	97.8	3	5.16	94.2	2	5.29
CC NS SP	10.8	4	4.79	17.7	3	5.16	37.9	2	5.29
CC NS SU	4.6	4	4.79	27.7	3	5.16	0.5	2	5.29
SW1 BL PL				98.7	3	5.16	99.5	2	5.29
SW1 BL SP				72.8	3	5.16	75.6	2	5.29
SW1 BL SU				79.2	3	5.16	85.5	2	5.29
SW1 PA PL				99.8	3	5.16	99.0	2	5.29
SW1 PA SP				71.5	3	5.16	58.7	2	5.29
SW1 PA SU				70.9	3	5.16	68.4	2	5.29
SW1 NS PL				99.5	3	5.16	98.5	2	5.29
SW1 NS SP				29.7	3	5.16	24.8	2	5.29
SW1 NS SU				25.3	3	5.16	7.0	2	5.29
SW2 BL PL				99.5	2	6.32			
SW2 BL SP				31.1	2	6.32			
SW2 BL SU				53.0	2	6.32			
SW2 PA PL				99.9	2	6.32			
SW2 PA SP				40.2	2	6.32			
SW2 PA SU				72.5	2	6.32			
SW2 NS PL				99.5	2	6.32			
SW2 NS SP				22.0	2	6.32			
SW2 NS SU				23.2	2	6.32			

[1] Logging method: CC, clearcut; SW1, shelterwood level 1; SW2, shelterwood level 2.
[2] Site preparation: BL, bladed; PA, patch scarification; NS, no scarification.
[3] Regeneration method: PL, planted; SP, seeded with protection; SU, seeded without protection.

above 95 percent, while germination, establishment and survival on seed-spots, regardless of protection, was less than fifty percent. Seeding without protection generally resulted in similar survival as seeding with protection. Site preparation contributed to higher germination and survival of seedings, but had little affect on survival of planted seedlings.

After three years, mean height growth increment for artificial regeneration (table 3) was greatest for planted seedlings regardless of site preparation. ANOVA indicated no difference between cutting methods on Site II or III (F = 0.35, $p < 0.722$ for Site I; F = 7.32, $p < 0.114$ for Site III). Annual growth apparently differs by site preparation and regeneration method; all site preparation and regeneration effects and interaction terms were significant. In addition, growth was also affected by vegetation type or site, as shown in table 4. These data suggest the need to restrict timber management to sites represented by Site III, and to emphasize containerized seedling reproduction with complete site preparation rather than spot seedings.

Recognition and management of timber resources by vegetation or site types that partition the variability in productivity and survival of regeneration may reduce costs associated with silvicultural activities.

REFERENCES

Dyrness, C. T.; Viereck, L. A.; Foote, M. J.; Zasada, J. C. [In preparation]. The effect on vegetation and soil temperature of logging flood-plain white spruce. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Table 3--Third-year mean height growth increment, by logging method, site preparation, and regeneration method, for three sites on Willow Island, Alaska. N represents the number of seedlings measured for each mean; SE is the standard error of the estimated mean

Treatment	Site I			Site II			Site III		
	Increment (cm)	N	SE	Increment (cm)	N	SE	Increment (cm)	N	SE
CC[1]BL[2]PL[3]	4.4	200	0.15	6.3	150	0.23	10.5	100	0.27
CC BL SP	1.4	200	0.15	1.2	150	0.23	1.8	100	0.29
CC BL SU	1.1	200	0.15	1.4	150	0.23	1.2	100	0.29
CC PA PL	4.1	200	0.15	5.7	150	0.23	8.6	100	0.28
CC PA SP	1.1	200	0.16	1.3	150	0.24	2.5	100	0.27
CC PA SU	0.8	200	0.15	1.0	150	0.23	1.1	100	0.27
CC NS PL	3.9	200	0.15	4.1	150	0.23	5.1	100	0.27
CC NS SP	0.1	200	0.15	0.3	150	0.23	1.5	100	0.28
CC NS SU	0.3	200	0.14	0.2	150	0.23	0.0	100	0.28
SW1 BL PL				8.4	150	0.24	8.8	100	0.27
SW1 BL SP				2.6	150	0.23	2.1	100	0.28
SW1 BL SU				2.2	150	0.23	2.2	100	0.27
SW1 PA PL				5.4	150	0.23	6.7	100	0.27
SW1 PA SP				1.8	150	0.24	1.1	100	0.27
SW1 PA SU				1.4	150	0.23	1.0	100	0.27
SW1 NS PL				3.6	150	0.23	5.7	100	0.27
SW1 NS SP				0.3	150	0.23	0.3	100	0.27
SW1 NS SU				0.2	150	0.23	0.1	100	0.27
SW2 BL PL				5.5	100	0.28			
SW2 BL SP				1.6	100	0.29			
SW2 BL SU				1.3	100	0.28			
SW2 PA PL				4.8	100	0.28			
SW2 PA SP				1.4	100	0.29			
SW2 PA SU				1.4	100	0.28			
SW2 NS PL				6.3	100	0.28			
SW2 NS SP				0.4	100	0.29			
SW2 NS SU				0.7	100	0.29			

[1] Logging method: CC, clearcut; SW1, shelterwood level 1; SW2, shelterwood level 2.
[2] Site preparation: BL, bladed; PA, patch scarification; NS, no scarification.
[3] Regeneration method: PL, planted; SP, seeded with protection; SU, seeded without protection.

Table 4--Mean growth increment (cm) by site and regeneration method

Regeneration method	Site I	Site II	Site III
Planted seedlings	4.1	5.6	7.6
Seedings - Protected	0.8	1.2	1.5
- Unprotected	0.7	1.1	0.9

Foote, M. Joan. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of interior Alaska. Res. Pap. PNW-307. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 108 p.

Putnam, W. E.; Zasada, J. C. 1986. Direct seeding techniques to regenerate white spruce in interior Alaska. Canadian Journal of Forest Research. 16: 660-664.

Viereck, Leslie A.; Dyrness, C. T.; Van Cleve, K. 1984. Potential use of the Alaska vegetation system as an indicator of forest site productivity in interior Alaska. In: Murray, Mayo, ed. Forest classification at high latitudes as an aid to regeneration. Proceedings of a fifth international workshop; 1983 August 15-17; Fairbanks, AK. Gen. Tech. Rep. PNW-177. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 25-34.

Zasada, John; Norum, Rodney. 1986. Prescribed burning white spruce slash in interior Alaska. Northern Journal of Applied Forestry. 3: 16-18.

Zasada, John C.; Slaughter, Charles W.; Teutsch, Christian E.; Argyle, J. Dean; Hill, William. 1987. Winter logging on the Tanana River flood plain in interior Alaska. Northern Journal of Applied Forestry. 4: 11-16.

Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., compilers. 1989. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17–19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 315 p.

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